U. S. SURGEON GENERAL'S OFFICE

WHAT YOU SHOULD KNOW ABOUT THE ATOMIC BOMB

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ATOMIC BOMB

A MESSAGE FROM THE SURGEON GENERAL

ARMY MEDICAL DEPARTMENT

The Doctor and the Atomic War

Much has been said of the need for public understanding of the new Atomic Age. A citizenry ignorant of the vast opportunities and of the crushing responsibilities inherent in the release of nuclear forces, is courting annihilation. In the future, only the informed nation will be safe.

Yet, important as it is for the average man to measure his obligations toward the future, it is far more important for the medical man to understand his. The responsibility of the doctor for the safety, for the sheer survival of great masses of the population, if a new conflict comes, is gigantic. For nobody seriously doubts that the next war will be fought with atomic bombs many times more devastating than those dropped on Japan.

We of the United States Army Medical Department fully realize the gravity of the new situation that confronts the physician and the medical research man. Though we fervently hope that there will not be an atomic war, we cannot assume there will never be one; on the contrary, we must act as though one were certain. We cannot leave to chance, or to hurried last-minute action, the technological preparations which alone will cut down the enormous casualties if these new bombs are dropped upon our closely packed civilian centers.

We are doing everything in our power to anticipate such a catastrophe by study, by training, and by research; by planning and by special organization of our medical forces. Through these efforts we seek to acquaint all civilian physicians of the procedures that will be necessary in time of emergency.

Our beginnings, to date, have been modest, but our efforts are growing daily. They consist, in the main, of utilizing every item of data and experience gained in the manufacture of the bomb in its use at Hiroshima and Nagasaki, at Bikini, and recently Eniwetok. We can say, even at this early stage, that our population need not be defenseless. The trained combination of nuclear physicists, engineers, and medical men *can* operate to protect our Nation if it is ever attacked.

In this little booklet we have brought together a series of articles based on lectures delivered during our first course in atomic medicine, currently sponsored by the Armed Forces Special Weapons Project. They were originally published in the *Bulletin of the U. S. Army Medical Department* and are collected here to give an over-all picture of our present thinking on the subject. We hope that every doctor, in and out of the Army, will take this message to heart, and will cooperate with us in a steady improvement of the defenses which we know we must prepare.

RWBliss

R. W. BLISS
MAJOR GENERAL, U. S. ARMY
THE SURGEON GENERAL

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Patient clothed. Charred parts of outer clothing have fallen away

Flash burns. Relation of burns to charred portion of clothing. Burns are most extensive where clothing was tightest

Jacket (burn marks on left sleeve) showing action of infrared rays. Less effect on white background

What Every Medical Officer Should Know About the Atomic Bomb

I. Introduction to Nuclear Physics

The atomic bomb has added a new terror and devastating force to the arsenal of war, and has increased the number of potential casualties which the Medical Department might be called on to handle in the event this weapon of destruction is employed in future warfare. National security makes it imperative that each Medical Department officer understand the fundamental facts regarding the medical effects of an atomic explosion. It is essential, therefore, that pertinent medical information on the problem be disseminated to those personnel who will be charged with the responsibility of caring for the sick and wounded resulting from the use of atomic weapons.

The electron. Units of negative charge of electricity, such as those used in any radio, electrons are produced by a hot filament in the tube elements. These electrons are evaporated from the glowing filament by the high temperature which is created in the filament. Careful measurements have shown that all of these electrons have the same physical properties. Furthermore, electrons produced from a glowing filament are exactly the same as electrons produced by other means, as, for example, by release from a photoelectric cell. The electron is the lightest particle known to man and weighs only 9×10^{-28} gm. The vast majority of all electrons found in nature are not "free" in the sense that they are not attached to something else, but are more or less tightly bound in a larger structure which is known as the *atom.*

The atom. An atom is the smallest part of a chemical element which enters into a chemical reaction. The concept of the atom as a structure which is mostly "space" is one which can be appreciated best by realizing the magnitude of atomic and nuclear dimensions. One gm. of hydrogen contains 6×10^{23} atoms. Thus, even if this gram of gas is contained in a very large vessel, the number of atoms per cubic centimeter is extremely high. Each hydrogen atom has a diameter of about 10^{-8} cm., or less than one hundred millionth of an inch. All atoms are composed of an inner part called the *nucleus* and an outer part called the *electron shell.* The hydrogen atom is conceived as consisting of a tiny nucleus about which circles a single *electron.* This nucleus of the simplest hydrogen atom is called the *proton.* A proton is simply a hydrogen nucleus and is formed by stripping off an electron from the hydrogen atom. The proton occupies negligible volume inside the hydrogen atom, even though it constitutes almost the entire weight of the atom. Its weight is 1,840 times greater than that of the electron.

The electrical nature of matter. Electrons are the only particles that are found within the atom outside of the nucleus, and, since they are negligibly small as compared to the atom, it is clear that the greatest part of the atom is a void. Why then should the atom possess such apparent shape or rigidity which we know from experience it must have? The reason for this lies in the electrical nature of the nucleus and of the electrons which speed about it in never-ending orbital paths. In every normal atom, the nucleus carries a positive charge of electricity which is exactly the same as the total negative charge of all the electrons within the atom. For convenience we call the charge carried by 1 electron $-e$ (it is actually 4.8×10^{-10} electrostatic unit). It is known that each electron carries a discrete electric charge of $-e$ unit. Each positive charged particle (proton) in the nucleus carries a charge of $+e$ unit. For any neutral (uncharged) atom the number of protons within the nucleus is exactly equal to the number of orbital electrons in the atom. Between the protons inside the nucleus and the electrons outside of it, there exists an electrostatic force which pulls the particles together. This force of attraction is just balanced by the centrifugal force caused by the whirling motion of the electrons around the nucleus. Thus the electrons perpetually gyrate around the nucleus in orbital paths through the frictionless void of the atom.

The outer part of the atom. Starting with the simplest atom, hydrogen with its atomic number 1, the number of orbital electrons is one. The *atomic number* (Z) of any atom is equal to the number of protons in its nucleus. For heavier elements, more and more electrons are found in the orbits. Helium with $Z=2$ has two electrons, iron with $Z=26$ has 26 orbital electrons, and uranium has 92 such electrons. These electrons arrange themselves in definite ways about the nucleus and obey rigorous atomic rules. Thus, they build themselves up about the nucleus in systematic shells that are peculiar in that each shell can contain just so many electrons. When one shell is filled, the electrons start another shell which is farther from the nucleus. The electrons which are in the outermost shell are called the valence electrons. These determine the chemical properties of the atom. Since these outer electrons are farthest from the nucleus, it is reasonable to suppose that they will not be bound so tightly to the atom. The outer electrons are in a sense shielded from the nuclear charge by the inner electron shells so they cannot "see" the nucleus. On the other hand, the electrons in the innermost or "K" shell are close to the nucleus and are thus most tightly bound to it.

Ionization of an atom. If by some means we could pull one of the outermost electrons away from an atom, the resulting atom would no longer be electrically neutral but would have a net charge of $+1$. The process of removing an electron from an outer shell is called *ionization* and the resulting atom is called an *ion*. The combination of the positive ion and electron is known as an *ion pair*. An atom can be ionized by shooting high speed electrons at it. These minute projectiles may collide with some of the outer electrons and knock them out of their orbits away from the atom. From a medical viewpoint the ionization process is of tremendous importance, since it is the part of the process by which tissue suffers radiation damage. By bombarding an atom with very high energy electrons, it may happen that an electron in a "K" shell will be knocked out, forming a vacancy which is filled by one of the outer shell electrons. In this process energy is liberated from the atom in the form of an *x-ray*.

X-ray emitted from atoms. The emission of an x-ray from an atom always occurs when an electron from an outer shell fills a vacancy in a "K" shell. Because the electrons in atoms of different elements are bound to their respective nuclei with different energy, the energy of the x-rays given off will depend on the element which is producing them. X-ray tubes may have different elements for targets, and the rays emitted from a tungsten target are much "harder" than those from a copper target. The energy of radiation for x-rays is usually measured in electron volts. An electron volt is that energy which is acquired by an electron in being accelerated across a potential of 1 volt. In x-ray tubes the electrons emitted by the filament are accelerated by about 100 kilovolts, and we therefore say that these electrons acquire 100,000 ev (electron volts) of energy. X-rays sometimes behave as though they were "particles" and sometimes they act like "waves." In the literature, x-rays are often called *photons* or *quanta*. It is a fundamental rule in physics that every particle has associated with it certain wave properties and can be described as having a definite wave length. Wave length in the x-ray region is usually measured in terms of 10^{-8} centimeters or *angstrom units* (A°). If an x-ray photon has an energy of, for example, 1 million electron volts (1 Mev) it is said to have a short wave length or to be a very hard x-ray. On the other hand, if it is a photon of only .03 Mev it has a relatively long wave length and is said to be "soft."

The inner part of the atom. The nucleus of the atom, while it is a dense sphere taking negligible space within the atom, is composed of smaller units or particles. One of these particles—the proton—has already been mentioned, but little has been said about it. In addition to protons, every atomic nucleus, except that of hydrogen, contains another type of particle—the *neutron*. The neutron differs from the proton in that it does not have an electrical charge. Both the neutrons and protons are about the same in weight and each is 1,840 times heavier than an electron. Therefore

the bulk of all matter is found within the nucleus. If you as an individual were suddenly to be disintegrated so that the nuclei in the atoms of your body were free to come together, all your weight could be concentrated in a speck on the end of a pin. Because the nucleus has its components so closely packed together, we say that it has high density. Along with this close packing of neutrons and protons, there must be some force which acts between these particles. Particles inside the nucleus are called *nucleons*. This force which acts between nucleons and holds the nucleus together is a queer type of force which is called *nuclear force*. It is this force that is responsible for the enormous energy which is locked up within the nucleus. The energy is usually called the "binding energy" of the nucleus since it binds the nucleons together in a compact system.

Gamma rays emitted from the nucleus. When the nucleus of an atom suffers a collision with a high energy atomic particle, it may become "excited" by virtue of having absorbed energy from the collision. One way in which the nucleus can get rid of this energy is by emitting a photon. This photon is called a *gamma ray* and differs from an x-ray only in that it is generally a higher energy photon. Otherwise a gamma ray emitted by a nucleus is identical with an x-ray. Once a nucleus emits a gamma ray, it may return to its former unexcited or normal state. Experimentally, many substances may be made to emit such gamma rays by irradiating them with a cyclotron beam or by placing them within a neutron reactor or pile.

Alpha and beta particles. About fifty years ago, it was observed that certain elements give off penetrating radiations. Elements such as uranium and radium give off a variety of radiations and are called radioactive elements. The phenomenon is known as *radioactivity*. Besides emitting gamma rays, these elements were observed to give off alpha and beta particles. *Alpha particles* are helium nuclei moving at high velocity. They are particles composed of two neutrons and two protons. Compared to an electron, such a particle is massive and might be expected to be easily absorbed in matter. This is actually the case, for most alpha particles are completely stopped by a few sheets of thin paper. This very short range of action for an alpha particle does not prevent it from being effective in damaging cell tissue. *Beta particles* are ordinary electrons which are emitted from nuclei. They move with high velocity (almost the speed of light) and are not as easily stopped in matter as are alpha particles. Beta particles of a few million volts energy will, however, be completely absorbed by several thin sheets of aluminum. Beta particles are created in the process of emission just as x-rays are created. Before emission, an atom does not contain an x-ray, and, in like manner, neither does a nucleus contain any electrons.

Radioactive transformations and isotopes. In the act of emitting an alpha particle, a radium (element 88) atom must undergo a change in its nuclear structure, for the two neutrons and two protons which make up an alpha particle are subtracted from it. Technically, we say that the radium atom undergoes a *radioactive transformation*. To facilitate an understanding of these phenomena, it is necessary to introduce some nuclear nomenclature. The radium nucleus is indicated by the symbol $88^{\mathrm{Ra}^{226}}$. Here the superscript is called the *mass number* and is numerically equal to the total number of neutrons and protons in the nucleus. The subscript 88 is the atomic number or *charge* and is numerically equal to the total number of protons in the nucleus. Elements such as tin ($Z=50$) have a variety of different weights since some tin nuclei have more neutrons than others. These atoms of tin which have different numbers of neutrons are known as *isotopes* of tin. *Thus isotopes are simply atoms whose nuclei have the same atomic numbers but different mass numbers*. Some elements have only one isotope; whereas others may have as many as ten isotopes, each of which is present in different proportions.

When $88^{\mathrm{Ra}^{226}}$ emits an alpha particle (symbolized by 2^{He^4} since it has atomic number 2 and four nucleons in its nucleus), it transforms itself into a new element known as *radon*. This reaction may be written: $88^{\mathrm{Ra}^{226}} \rightarrow 86^{\mathrm{Ra}^{222}} + 2^{\mathrm{He}^4}$ (Radium

goes to radon plus alpha particle). Analogous to chemical equations, it is possible to balance the equation and obtain a resultant atom of radon which has $Z=86$ and a total number of necleons equal to 222. Instead of referring to this process as a radioactive transformation, we can also call it a *radioactive decay or disintegration.* The decaying isotope is the "parent" and the disintegration product the "daughter."

Radioactive series. Radium is only one of the many radioactive isotopes which occur in nature. Radium is itself the daughter of a thorium isotope which in turn is a daughter of a uranium isotope. There is thus a chain or series of isotopes that are respectively parent and daughter to each other. The radon that is formed from radium is also radioactive and decays to form polonium, and this forms an isotope of lead.

$$92^{U^{234}} \xrightarrow{a} 90^{Th^{230}} \xrightarrow{a} 88^{Ra^{226}} \xrightarrow{a} 86^{Rn^{222}} \xrightarrow{a} 84^{Po^{218}} \xrightarrow{a} 82^{Pb^{214}}$$

The a over the arrow indicates that an alpha particle is emitted in the decay process.

Lead is commonly thought of as a very stable element. By that is meant that it does not undergo radioactive decay. However, the isotope of lead that is formed in this radioactive series above is not stable. It has 214 nucleons in its nucleus, and since it must have 82 protons, there are 214–82 or 132 neutrons in the nucleus of this atom of lead. In the lead atoms found in nature the heaviest isotope is $82^{Pb^{208}}$. Thus the isotope $82^{Pb^{214}}$ is much heavier than the heaviest natural lead isotope for it contains six additional neutrons. Instead of emitting an alpha particle which would make the *neutron surplus* even worse, the lead isotope $82^{Pb^{214}}$ emits a beta particle, and the reaction is as follows:

$82^{Pb^{214}} \longrightarrow 83^{Bi^{234}} + -1^{e^{0}}$ (Lead goes to bismuth plus electron). In this case, lead changes to an element of a higher atomic number, since the emission of an electron is equivalent to *adding* a charge of $+e$ to the lead nucleus. In these nuclear reactions the electric charge is always equal on each side of the equation. Since the electron has negligible mass, the atomic weight of the isotope of bismuth is the same as the parent atom. By succeeding beta and alpha emissions the bismuth atom is finally transformed to a stable isotope of lead, $82^{Pb^{206}}$. This isotope is then the end of this series, which is called the uranium series. It must be remembered that in these decay processes penetrating gamma rays are also emitted; but, since gamma rays have no charge and no real mass, they do not affect the series relationships. In addition, two other naturally radioactive series are known—the thorium and the actinium series, both of which finally decay to stable isotopes of lead.

The rate of radioactive decay. Does the radium atom, for example, disintegrate in one second or in one year? Actually the process is statistical in nature, and, if one were able to look at one isolated radium atom, one might see it decay in a minute or one might have to wait a million years for it to disintegrate. If, however, we look at 1 gm. or 2.6×10^{21} of radium atoms, we find that there is an average value for the time in which 50 percent of these atoms will decay. This time is called the *half life,* and for radium it is 1,590 years. If we start out with 1 gm. of radium, then in 1,590 years we shall have only 0.5 gm. on hand. Radium is said to be long-lived, but other atoms have extremely short half lives of the order of one-millionth of a second. Still others, like $92^{U^{238}}$ (the heavy isotope of uranium), are long lived, having a half life of 490.5 years.

In order to calculate the activity of any sample of a radioactive material, multiply the number of atoms present as follows:

$$\text{Activity} = \frac{\text{(No. of atoms)} \quad (.69)}{\text{Half life (in seconds)}} = \text{Number of particles emitted per second.}$$

The activity of 1 gm. of radium can be calculated as follows: 226 gm. of radium are equal to 6×10^{23} atoms. Therefore, 1 gm. contains 2.6×10^{21} atoms, and since the half life is 1,590 years or 5×10^{10} seconds:

$$\text{The activity of 1 gm. of RA} = \frac{(2.6 \times 10^{21})\ (.69)}{5 \times 10^{10}} = 3.7 \times 10^{10} \text{ disintegrations/second.}$$

The unit of measure of this activity is the *curie*. The millicurie (mc.) unit is one-thousandth of a curie. A millicurie of radium gives off 37 million particles in one second.

The quantity of radiation. In treating a patient with radiation from a radium capsule it is necessary to measure the dose which is given. For this purpose the unit is the *roentgen* (r.), which is defined as that quantity of x-radiation which on passing through 1 cc. of normal air produces 1 electrostatic unit of ions. While it was originally defined only for x-rays, the definition is equally valid for gamma rays. A smaller unit, the milliroentgen (mr.), is often used in practice. The definition is perhaps not too meaningful because of the term—electrostatic unit—which is used. Physically, one should think of the definition as meaning that quantity of x-rays which is measured by a certain number of ions produced in a standard volume of air (roughly, 2 billion ion pairs per cubic centimeter of air).

Different types of instruments can be used to measure x-radiation. These are ionization chambers, Geiger-Muller counters, and photographic emulsions. One should sharply distinguish between those instruments that measure the dose or total quantity of radiation and those which give the dose-rate or the intensity of radiation. Dose is measured in roentgens, whereas dose-rate is measured in roentgens per second or in other time units. It is one thing to give a patient a dose of 1 r. of x-rays and quite another to expose a patient to a dose-rate of 1 r. per second. In the latter case, the patient receives a 1-r. dose in one second and a 60-r. dose in one minute. In one hour the patient would be dead or fatally injured.

NUCLEAR FISSION AND THE CHAIN REACTION

We are now prepared to discuss nuclear fission. If by some process the compact atom nucleus can be split, it is known that part of the mass of the original nucleus will be transformed into energy. To appreciate this, we must discuss the mass-energy relation which was first put forth by Einstein.

The mass-energy relation. If in any reaction there is a decrease in mass of the reaction, Einstein's mass-energy equivalence law states that this mass is converted into some form of energy. The resultant energy may be evident in any of several ways. For example, radiation may be emitted as in gamma ray emission (radiant energy) or particles may be given high velocity (kinetic energy). In any event, $E=MC^2$ where E is energy released, M is decrease in mass and C is velocity of light. Let us assume that a uranium-235 atom ($92^{U^{235}}$) is split into two parts and that one-fourth of a mass unit is converted into energy. One mass unit has about the weight of one proton and is equal to 930 million electron volts of energy. One-fourth of a mass unit, then, amounts to about 230 Mev. Since the original $92^{U^{236}}$ atom weighs 235 mass units, it is equivalent to a total energy of 220,000 Mev. Thus only about $\frac{1}{1,000}$ of the total energy content of the uranium atom is released in this process. In fission, the greatest part of the 230 Mev of energy is released in imparting high velocity to the split atom parts *(fission products).*

A physical picture of the nucleus. In the foregoing, we have indicated something of the nature of the nucleus. We can form a very useful model or picture of the nucleus by thinking of it as analogous to a water droplet. Inside the confines of such a sphere, the neutrons and protons are in a constant state of violent motion, bumping into each other incessantly but always remaining inside the sphere. So strong are the forces between the nucleons that they pull each other tightly together and do not let each other out of "view." As evidence of this close packing of neutrons and protons inside the nucleus is the fact that the uranium-238 atom (the heaviest naturally occurring isotope) is only slightly larger in diameter than the nucleus of a light element such as aluminum. Outside the nucleus, the extremely strong

nuclear forces are not felt because they have a very short range of action. However, the protons inside the nucleus make themselves known outside the confines of the nucleus by their electrostatic field. This field forms a barrier around the nucleus which prevents any charged particles from entering the nucleus. If, however, the particle which seeks to enter it is uncharged, it cannot "see" the particle and offers no resistance to its entry. For this reason, neutrons of low energy can easily slip inside the nucleus, whereas protons of even very high velocity are barred.

A model of the fission process. It is a property of a few very heavy nuclei such as U-235 that, when a neutron is added to them, they react very violently by splitting into two almost equal parts. The process is called *nuclear fission,* and the isotopes which exhibit this unusual behavior are called fissionable. The heavy products of the fission reaction, i. e., the two halves of the heavy atom, are known as *fission products.* We can picture the fission process by again considering the liquid drop model of the nucleus. Let us imagine that before the neutron enters the U-235 nucleus all the 92 protons and 143 neutrons are in constant motion inside the spherical nucleus. Let us assume that, because the nucleons are so close together and move so rapidly, they lose their individual identity and may be thought of as forming a fluid or liquid drop of uniform density. With the intrusion of a neutron into this balanced system, the liquid drop has energy added to it and becomes "excited." The particles inside the nucleus are set into more violent motion and the drop begins to lose its spherical shape. As it deforms into a nonspherical shape it sets up rapid oscillations that deform it still further into a dumbbell pattern. At this point the original sphere is essentially drawn out into two smaller spheres with a tenuous connecting link that then snaps. Then the two fission products shoot away from each other with high velocity. All this happens in an interval of less than 10^{-12} second and may be thought of as an instantaneous reaction.

Neutrons released in fission. When fission occurs neutrons are released. Over 99 percent of these neutrons are emitted within less than 10^{-10} second, but a small fraction of 1 percent are delayed for as much as one minute after fission has occurred. All neutrons, whether prompt or delayed, are emitted by the fission products. In addition to neutrons, gamma rays, beta particles, and sometimes alpha particles are emitted in the fission process. A reaction equation for a fission process can be expressed as follows:

$$_{92}U^{235} + {_0n^1} \longrightarrow {_{46}Pd^{117}} + {_{46}Pd^{117}} + {_0n^1} + {_0n^1}.$$

(Uranium-235 plus neutron gives 2 palladium isotopes plus 2 neutrons.)

This assumes that the nucleus splits into two equal parts. If one looks in a table of stable isotopes one finds that the heaviest natural isotope of palladium is $_{46}Pd^{110}$, while the palladium isotopes shown in the reaction equation are much heavier, having seven more neutrons per atom. From experience, we know that these abnormally heavy isotopes are not stable and must by some means make up for the abundance of neutrons in their nuclei. This can also be thought of as a deficit of protons in the nucleus. It is thus understandable that neutrons are so quickly emitted by the fission products.

Radiations from fission products. In natural fission it is rare for a pair of fission products to have the same mass, and it is much more common for one of the products to be heavier than the other. In general, there are two groups of fission products, one with an average mass of about 95 and the other of about 139. Fission products are intensely radioactive, emitting high energy beta particles and gamma rays. By emitting beta particles, the isotopes which contain too many neutrons (or too few protons) tend to make themselves more normal, since beta-emission is equivalent to changing a nuclear neutron into a proton. Because the fission products are born with such extreme neutron excesses, it requires four or five separate beta decays to result in stable atoms. Thus, each fission product is often associated with a chain of radioactive isotopes, and for this reason we speak of these as *fission chains.* Almost all fission products emit very penetrating gamma rays in addition to beta particles. The half lives for the various fission products

vary from a fraction of a second to many years. The result of fissioning a large number of atoms is that we have an aggregate of many different fission products representing almost every element from atomic number 40 to 70.

The chain reaction. If we wish to talk about the fission of large numbers of uranium atoms, it is necessary to have large numbers of neutrons available. Because the fission process requires only one neutron to initiate it and yet gives off between one and three neutrons per fission, it is possible to use fission neutrons to start a chain of fission reactions. Each fission adds more neutrons to the reaction so that more and more reactions are possible. Such reactions are called self-sustaining or chain reactions. Since the fission process occurs so quickly, it is conceivable that, if we were to assemble a certain "critical" mass of fissionable material such as U-235, we could set off a series of fissions that would proceed so quickly that the recoiling fission products and radiations would raise the critical mass to a multimillion degree temperature within a fraction of a second. By definition, such a process would be explosive in nature. It is important to emphasize that the recoiling fission fragments that move with high speed cause the material through which they move to become hotter by kinetic collisions with other atoms. It is this heat caused by the motion of the fission fragments that causes an explosion to result. In like manner, if the energy is released at a slower rate, the heat may be tapped to be converted into power.

Prior to World War II, no pure U-235 was available. Ordinary uranium contains 140 times more U-238 than it does U-235. U-238 is not suitable for a chain reaction, because when it absorbs a neutron into its nucleus it merely changes into a heavier element without fissioning. Since the two isotopes of uranium are chemically identical, they can be separated only by exceedingly difficult physical methods. In fact, the methods presented so many technical obstacles that the Manhattan Project set up huge plants which used nuclear reactors running on natural uranium to generate a new man-made fissionable material—*plutonium* (Pu) ($Z=94$).

Plutonium. With neutrons released in the fission of the small amount of U-235 present in natural uranium, it was possible to sustain a chain reaction in a massive graphite-uranium pile. Under proper conditions a large number of the fission neutrons released in the pile can be absorbed by the U-238 atoms. This results in an unstable U-239 nucleus that rapidly decays by beta emission as follows:

$$_{92}U^{238} + {_0n^1} \longrightarrow {_{92}U^{239}} \longrightarrow {_{93}Np^{239}} + {_{-1}e^0}.$$

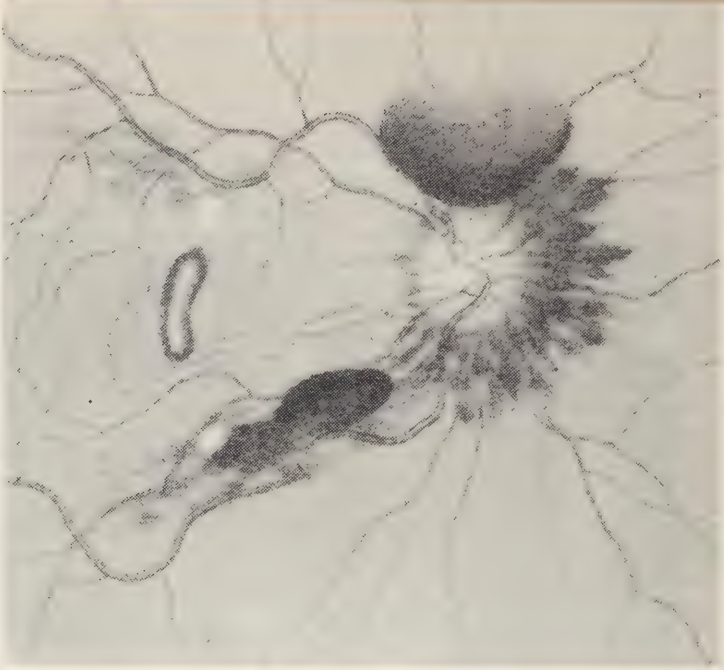
(Np is the symbol for *neptunium.*)

Neptunium is itself radioactive and soon decays to form an isotope of element 94 which has been named plutonium. Thus:

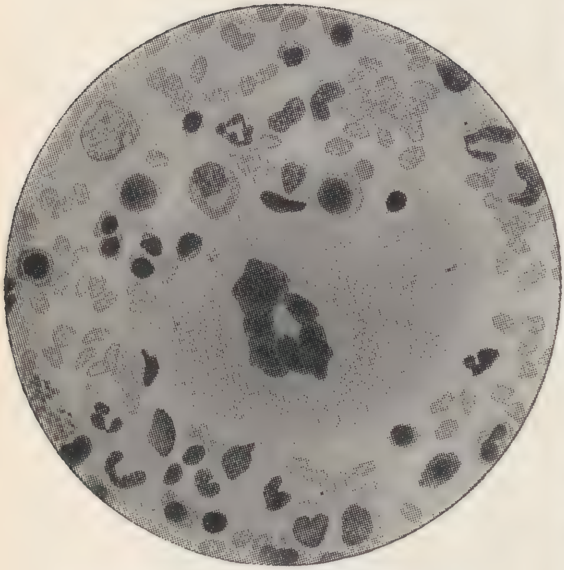
$$_{93}Np^{239} \xrightarrow{2.3d} {_{94}Pu^{239}} + {_{-1}e^0}.$$

The figure 2.3d over the arrow means that this reaction has a half life of 2.3 days. Plutonium is a dense silvery metal similar to uranium U-235 in that it is fissionable with neutrons which are of low energy. Like U-235 it is also an alpha emitter, and, since it has a half life of 24,000 years, it is much more active than U-235, which has a half life of 7×10^8 years. The alpha activity of plutonium is sufficiently intense so that it constitutes a serious health hazard of about the same type as radium when it is deposited in bone.

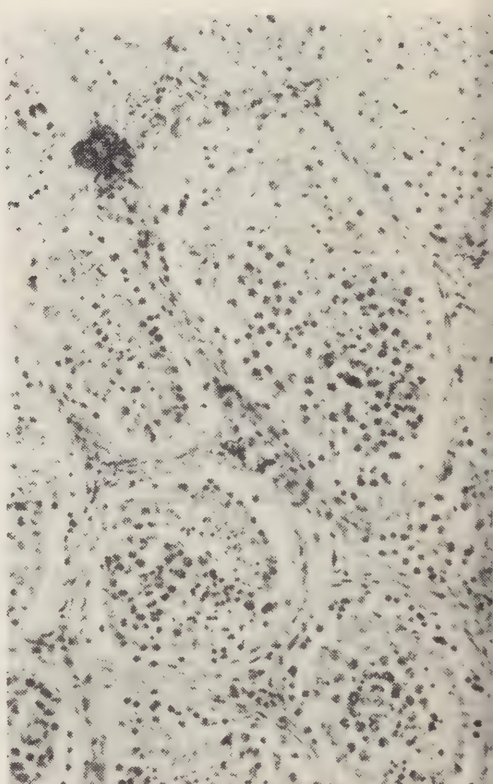
The concept of critical size. One of the unique characteristics of an atomic explosive is that it must be assembled into a certain critical size before it can explode. The reason for this unusual characteristic is that the chain reaction will not be self-perpetuating unless there are sufficient neutrons to cause continued fission. Suppose, for example, we wish to run a chain reaction at a rate of 500 fissions per second and that each fission generates exactly two neutrons. This requires that one out of every two neutrons generated be used to create more fission, so that we have to have 500 neutrons being used every second to cause fission. This leaves an additional 500 neutrons which we can afford to "lose" from



Hemorrhage of the retina



Sternal bone marrow 76 days after bombing, showing good regeneration of all elements



Testes, showing destruction of sperm-producing cells

our system either by absorption not leading to fission or by loss through escape from the system. When the number of neutrons being produced over and above those needed to keep the fission reaction going at a fixed rate is exactly equal to the number of neutrons lost from the system, we say that the system is critical, and this mass of material is called the critical mass. Masses less than this are called subcritical and larger ones are known as over-critical masses. The trick in detonating an atomic bomb is to make an assembly of fissionable material over-critical as fast as possible and keep it together long enough so that an appreciable fraction of the atoms is fissioned. If one simply stacked up subcritical blocks of U-235 until the assembly was overcritical, the chances are that no explosion would result. There would be a neutron "flash" and the heat generated by the fission of a small fraction of the atoms would push the blocks apart and make the assembly noncritical. The neutron flash would, however, be a source of danger.

The atomic bomb. A logical way to assemble an atomic bomb might be to take two hemispheres of fissionable material each of which is subcritical and bring them very quickly together to form an overcritical mass. One hemisphere of pure U-235 might be imbedded in a large mass of material placed at the target end of a gun barrel. At the other end of the barrel might be another hemisphere which serves as a projectile. Separated by the length of the gun barrel, each hemisphere would be subcritical and safe, but by firing the one hemisphere down the barrel, it would attain a high velocity and weld itself together with the target into an over-critical mass. The inertia of the projectile together with the force of the expanding gas behind it might hold the system together for an appreciable length of time so that a large amount of the uranium is fissioned. This might insure a high "efficiency" for the reaction. While it is not possible to calculate the exact magnitude of the activity associated with the radiations emitted by an atomic explosion without revealing classified information, it is possible to make crude calculations based on very simple assumptions. These show that the radioactivity which results from an atomic detonation is equivalent to more than 1 million tons of radium.

Radioactivity induced by neutrons. If a neutron strikes a nucleus of some element such as sodium, it may be absorbed or captured by it. This process is described by the reaction equation: $_{11}Na^{32} + {}_{0}n^{1} \rightarrow {}_{11}Na^{24}$. The resulting sodium atom is not normal and emits radiation. For this reason it is called radiosodium. Radiosodium emits a beta particle of 1.4 Mev and also a gamma ray. Thus, if an atomic bomb explodes close to sea water there will be a neutron-induced activity produced, since salt in the sea water is present to about 35 gm. per liter. Radiosodium has a half life of 14.8 hours, and for this reason the activity will persist for a few days before becoming negligible in intensity. Other elements can also be activated by neutron irradiation. This is the means by which carbon-14, radioiodine, and radiophosphorus are made.

II. Biologic Effects of Nuclear Radiation From an Atomic Explosion

The discovery of x-ray by Roentgen in 1895 opened to the world the field of ionizing radiation. In 1896, natural radioactivity was discovered by Becquerel while studying the fluorescent effects of different substances. While working with uranium, he found that photographic paper was darkened, and the air adjacent to the salts would conduct electricity and discharge an electroscope. In 1898 the Curies isolated radium from pitchblende. It was soon after the discovery of x-ray that Becquerel noted the biologic effects of radiation on skin. He carried a vial of radium in his vest pocket and discovered a burn on the underlying skin. This was the first indication of a biologic hazard. In the next decade, radiation was used extensively as a therapeutic measure on almost every known disease and frequently with disastrous results. It was not until 1903 that evidence of the

marked sensitivity of the blood-forming organs and the reproductive organs of animals sounded the first warning that other than skin effects were occurring. Since that time the use of x-ray and radium has been approached with appropriate caution. This is mentioned to show that radiation is not a new problem introduced by atomic explosions. The increased seriousness of the radiation problems, has, however, stimulated greater interest in studying the effects of radiation and especially the mechanism by which radiation produces biologic effects.

Mechanism of ionization. The radiations with which we are concerned are gamma rays, and alpha, beta, and neutron particles. The effect they produce on living cells is known as "ionization." A ray or particle strikes an atom within the cell, breaks off a negatively charged electron, and results in a positively charged atom which, with the negative electron, is known as an *ion pair*. It is the formation of the ion pair that produces the biologic changes in the cell. The different radiations act differently to produce ionization. Beta and alpha particles directly ionize by applying their kinetic energy in striking and dislodging an electron from the orbit of an atom. Gamma rays and neutrons must pass through an intermediate step. Gamma rays strike a free or lightly held electron and impart kinetic energy to that particle which, in turn, ionizes the tissue. Similarly, neutrons collide with nitrogen or hydrogen atoms in the tissue and strike off a proton which, as a secondary particle, ionizes the tissue. The end result in either case is the formation of ion pairs in the cell.

Before considering radiation effects, the quantitative unit of radiation must be understood. It is called a roentgen (r.) and is the quantity of x-ray or gamma radiation that will produce in 1 cc. of air, under standard conditions, ions carrying 1 electrostatic unit of electricity of either sign.

Generalities concerning biologic effects. Practically all radiation effects are either definitely injurious or of no value to the individual from the standpoint of survival or competition. Some injurious effects are permanent and some temporary. Injurious effects vary widely in their severity. Ionizing radiation produces not one, but many different effects, even on the same species or organism. Some effects of radiation may appear in the descendants of irradiated individuals. Injurious effects may be beneficial as in the treatment of cancer, a balance being sought between the beneficial destruction of cancer and the injurious effects to the surrounding healthy tissue. An interesting paradox is presented here. Although irradiation will destroy cancer, it will also, under some conditions, produce cancer, as in the skin from repeated dosage.

External and internal radiation. In external radiation the source is outside the body and the radiation must pass through the skin to produce effects. With an external source, the radiation effect may be stopped by removing the source, moving away from the source, or by interposing adequate shielding between the body and the source.

In internal radiation the source is taken into the body by ingestion, inhalation, or through a break in the skin. The fission products or other radioactive elements are then deposited in the various organs of the body, the most important being a deposition in the bones in proximity to the bone marrow. When radioactive material is fixed in the tissue, it is excreted very slowly and so remains a constant source of radiation bombardment within the individual. There is no known process that will destroy or neutralize the radiation source, and methods to increase the excretion of the fixed material are unsatisfactory. The only limiting factor, other than excretion, is the normal decay rate of the radioactive element.

Tolerance levels. Past experience in the clinical use of x-ray and radium and laboratory experience in nuclear radiation have developed a level of radiation that is considered safe to absorb over a long period. This has been set at 0.1 r. per day of gamma or an equivalent amount of the other ionizing radiations. In all industrial processes an effort is made to stay within this maximum permissible dose.

With regard to internal radiation, the goal is no absorption. Specifically, in plutonium work, 1 mcgm. fixed in the bone is sufficient to require complete withdrawal from radiation work for life. A historic example of internal radiation injury is the occurrence of bone cancer and death among radium dial painters. The tolerance dose for radium fixed in the bone is only 0.1 mcgm.

Lethal dose. The lethal dose is fairly well established, and current thinking places the minimum dose that will be lethal for 50 percent of individuals (L. $D._{50}$) at 400 r. and the L. $D._{100}$ at about 600 r. When we speak of 400 r. as being lethal, we are speaking of irradiation of the entire body or total body radiation. Doses up to thousands of roentgens may be given to a small confined area of the body without causing serious injury except to the exposed area. The long-term effects of radiations ranging from the tolerance to the lethal dose are still obscure and the subject of some concern.

Biologic effects in tissues. Many theories have been advanced to explain injury from ionization, but the mechanism is still unknown. Among the more common are: (1) some chemical exchange that interferes with the normal interchange between the nucleus and the rest of the cell; (2) changes in permeability of the cell membrane; (3) production of a toxic substance in the cell; and (4) changes in the intercellular environment. When and if the true mechanism is discovered, we shall have a more substantial basis for recommending therapy, dosage, and possibly protective measures.

A single cell consists of several microscopically distinguishable parts that differ in chemical make-up. Since, under most conditions, all these parts are irradiated simultaneously at random, it is not surprising that many effects may sometimes be observed in the same cell. Some of these effects, such as chromosome breaks, increased granularity of protoplasm, change in affinity for various stains, cytolysis, swelling of the nucleus or the entire cell, can be directly observed by various microscopic techniques. Less direct physical methods reveal other effects, such as changes in viscosity of the protoplasm, or in the permeability of the cell membrane. It seems probable that only a small fraction of the cellular effects produced has yet been observed. The complexity encountered in the observation of cellular effects is increased many fold when we attempt to observe or analyze the effect on the many-celled organism. Here we irradiate many different types of cells and tissues, each of which may exhibit its own pattern of effects. This becomes further involved with the possibility of a radiation effect on one tissue producing an indirect effect on others.

A latent period is frequently mentioned that is really a misnomer. It is the period that elapses between the time the tissue is irradiated and the effects manifest themselves. Obviously, this period is not latent, but one in which numerous successive changes are occurring, which eventually lead to observable changes. Concerning the nature of these intermediate changes we are in practically complete ignorance. The various body tissues are listed in the order of their sensitivity to radiation: (1) lymphoid tissue, bone marrow, lymphocytes, lymph nodes, and Peyer's patches; (2) polymorphonuclear leukocytes; (3) epithelial cells of the gonads, salivary gland, skin, and mucous membranes; (4) endothelial cells, blood vessels, and peritoneum; (5) connective tissue cells; (6) muscle cells and (7) nerve cells.

Tissue responses to radiation. Concerning the sensitivity of tissues in general, the more primitive cells (leukocytes and reproductive cells) are more sensitive to radiation than highly specialized cells (brain cells). Whether the effect of ionization is direct, taking place within the cell, or indirect, resulting from alterations in the environment, is still a matter of conjecture. Both mechanisms may be active. The effect of radiation on extremely radiosensitive tissue is diminished when the tissue is subjected to decreased oxygen supply. Freezing definitely decreases radiosensitivity.

The recovery of damaged tissue depends on the dose absorbed and the type of tissue. Beyond a certain quantitative absorption of radiation, the cell will die regardless of type. The reversibility of any specific effect is dependent on reparative and regenerative properties of the tissue. Muscle, brain, and portions of the kidney and eye cannot regenerate. Repair results only in scar formation. Other tissues, such as blood-forming elements, membranes lining body cavities or glands, depending on the dose, may regenerate and resume their normal functions; but tissues that have been damaged and regenerated may not respond after repeated ionization, which makes it imperative to avoid a repetition of the injury.

One of the peculiarities of radiation is the variation in response of the different species and between identical cells or tissues of the species to the same dose of radiation. Because of this characteristic, it is impossible to measure effects in terms of severity to a single specimen, and statistical methods of measuring must be applied. The most convenient way of measuring most effects is to set up as a criterion some occurrence that may be classified simply as present or absent, such as inhibition of cell division, failure to grow, or death. Graded doses are given to various groups of biologic subjects, and, after the exposed cells or organisms have been scarred, injured or uninjured, the percent of uninjured cells is plotted against the dose. This gives a survival curve. The term survival here denotes the ability to perform a certain normal act in spite of irradiation.

An example of species variation can be seen in the following figures. The doses of x-rays required to kill 50 percent of the animals were as follows :

Mice	500 r.
Guinea pigs	250 r.
Rabbits	825 r.

This species difference is unfortunate, because we need quantitative information concerning radiation effects on man; but we are unable to draw quantitative conclusions concerning man from the results of experiments on laboratory animals. Species variations reduce such conclusions to a semiquantitative status.

The response to the *rate of radiation* falls into three categories: (1) Many biologic effects with a given dose are the same regardless of the rate at which it is delivered. Some genetic effects fall in this category. (2) In some cases, a given dose produces greater biologic effects if the rate of delivery is decreased. This has been explained by postulating that during prolonged radiation radiosensitivity may increase. (3) In the remainder—about 50 percent—of the biologic effects, the effectiveness of a given dose decreases as the rate of exposure decreases. This has been explained by assuming a decrease in radiosensitivity or a recovery factor. Most known injurious effects fall in this category, which is fortunate, since otherwise the daily tolerance dose would have to be set lower than it is at the present, so that it would be impossible for an injurious cumulative dose to occur in the maximum employment of an individual in the vicinity of sources of radiation.

The *distribution and penetration* of radiation will cause the biologic response to vary. To produce damage, the radiations must reach the vital tissues. Since alpha particles (heavily charged) are highly ionizing, they are about 10,000 times as effective as gamma rays, but the range of action is limited by their poor penetration (about 0.1 mm. in tissue). This eliminates alpha particles as an external hazard as they may be shielded out with a piece of paper or the skin, but when they are deposited internally in the bone marrow, severe damage because of their high ionizing ability results. Beta particles have a similarly poor penetration (about 5 to 10 mm. in tissue), but are also dangerous internally. Since they have a strong caustic effect on skin at short distances, they must also be considered among the external hazards. High energy gamma rays have a much less degree of ionization per centimeter of the distance they travel than alpha or beta particles, but their ability to penetrate and reach the deep tissues makes them a paricular hazard in external radiation. Neutrons are also penetrating (depending on their energies), and their

power of ionization is about five to six times as effective as that of gamma rays, which places this particle among the serious external hazards.

There follows a comparison of relative quantities of various qualities of radiation required to produce erythema, showing that the higher energy rays produce their ionization in the deeper tissues, and, in order to produce a skin effect, must be given in higher doses:

Radiation range	Exposure required to produce erythema
Grenz rays	100 r.
100 kv. x-rays	350 r.
200 kv. x-rays	600 r.
1,000 kv. x-rays	1,000 r.
Gamma rays (radium)	2,000 r.

Acute and chronic radiation. The acute must be separated from the chronic in any discussion of radiation injury. Acute injury results from large doses that produce clinically recognizable effects. Chronic injury results from doses ranging from the tolerance levels to about 10 r. a day. This is the subject of intensive research, but little data on man are as yet available. The results of animal experiments must suffice, because of the unsuitability of exposing human beings to this relatively unknown hazard. The most predominant effects expected of chronic radiation are shortening of the life span, premature aging, the production of malignancies; skin changes from beta, soft gamma, and x-rays; and genetic injury. In man it is said that radiologists and industrial workers exposed to x-ray show an increased incidence of leukemia. In mice, however, using doses ranging from tolerance to 8 r. a day, the latest reports indicate that the incidence of leukemia and lung tumor is not increased; when they occur, it is at an earlier age. The higher the rate of radiation, the earlier the onset. On the other hand, ovarian tumors do not depend on the rate of radiation, but on a minimal dose starting the process, the future course of which is not influenced by radiation. This minimal dose is cumulative, irreversible, and results in a higher incidence of tumors. Injury to mouse testes, however, is found to be reversible and only slightly responsive to cumulative dosage. Increased intensity of radiation over a short dose period will increase the damage.

The above findings have not been given to confuse the picture, but to illustrate the variation in responses of different tissue and the difficulty of attempting to evaluate the chronic effects of radiation on man.

Blood. Observations of the blood count should reflect injury to the blood-forming tissues. This is true for severe overexposure. Alterations in the blood picture may be observed within an hour after total body radiation. There is an initial leukocytosis that is followed by leukopenia with a relative decrease in lymphocytes and, several days later, a reduction in the erythrocyte count. An anemia is a manifestation of severe bone marrow damage and is often fatal. For exposure to small quantities of radiation, the leukocyte count is not a reliable index. The daily normal variations, existence of low-grade infections, and variations in counting technique are among the factors reducing its reliability in measuring the relatively small variations to be expected. A count on an individual exposed to frequent radiation showing a reduction, even when compared to the individual's previously established normal, is not a positive indication of radiation injury. The only importance that can be attached to a slight reduction in count would be that seen in an individual who is a member of a group exposed to radiation in which all show the same variation. That would possibly indicate an overexposure to radiation for the group.

Reproductive organs. The elements of the reproductive organs that are injured by radiation are the progenetors of the mature germ cells and the genes that transmit the hereditary factors. Permanent sterility can readily be produced by exposure to about 800 r. in the male and 600 r. in the female. Temporary sterility may be produced by much lower doses.

Genetic injury. Genetics is a complicated and somewhat obscure science. Although genetic injury is especially important because the effects are produced by cumulative dosage without regard to dosage rate or wave length, little is known of the actual genetic effects to be expected. Its study is complicated by the long life span of human beings, the small number of offspring, the lack of knowledge of the specific dose received, and the difficulty of controlling experiments. Much of the information now available is the result of studying the fruit fly and various species of fish, the direct application of which to man is difficult.

In general terms, the gene is a germinal factor that carries hereditary characteristics. There are dominant and recessive genes. Recessive genes must be contributed by both parents if the characteristic is to appear in the offspring, while the dominant genes may be contributed by either parent or both. Mutations are changes from the normal within the genes and may be deleterious or beneficial to the race. Mutations may occur naturally or may be produced by radiation. Mutations in dominant genes may be detected in the next generation, while recessive mutations may go undetected for several generations. Since the majority of both natural and radiation mutations are recessive, little change can be expected in the first generation, and, being recessive, the probability that they will manifest themselves in a future generation is relatively small. In about 95 percent of mutations, whether spontaneous or radiation induced, the offspring will die during gestation or shortly afterward. Of the viable 5 percent, about 95 percent are deleterious, and, of these, about 96 percent pertain to other than sex chromosomes. The remaining are sex-linked mutations that are the exception to the general rule of recessives requiring generations for expression.

In Japan, the total dose received by the survivors of the atomic bombs of 6 and 9 August 1945 was very low for clear-cut genetic effects; but in the next twenty years, through the sex-linked mutations, a change in the male-female ratio may be seen. Ordinarily, more males are born than females, but radiation may cause a decrease in male offspring. The occurrence of defective offspring may increase the stillborn birth rate, and there may be an increase in infant mortality because of congenital abnormalities. All this is being studied in Japan on a long range program being planned by the National Research Council. Many years, however, will be necessary before significant results can be obtained and evaluated.

III. Medical Effects of Atomic Explosion

Medical effects from the atomic bomb may roughly be divided into three categories: (1) trauma, (2) burns, and (3) radiation injury.

TRAUMA

Trauma was inflicted by the mechanical force of the explosion, either as blast or indirect trauma from flying debris. As in the case of the bombing of Britain, the latter was much more important.

Blast. The atomic explosion differs from an ordinary bomb blast in the extent of its range. No one was closer than several hundred meters to the bomb. At that distance the peak pressure must already have fallen, and its duration must have greatly decreased in comparison with what it was in the center. The explosion did not have the triphammer blow effect of high explosive, but was rather like a sudden violent gust of air that lasted for a brief but appreciable period. Japanese medical observers on the spot could not find any patients with direct damage to the internal

organs caused by the blast. Necropsy of the early cases showed no evidence of blast damage to the lungs. Many persons reported having lost consciousness temporarily, with no history of direct trauma to the head. Observations tend to discount cerebral concussion resulting directly from the blast. A report shows a total of 17 ruptured eardrums at Hiroshima and 22 at Nagasaki. According to British investigators there is a great variation in the intensity of the blast pressure that will result in the rupture of the eardrums in man. In explosions where persons were subject to pressures of 45 to 100 lbs. per square inch, less than half of a small group suffered rupture of the tympanum. The drum may, however, rupture under pressures as low as 2 to 4 lb. in excess of one atmosphere (g). The acceleration of the pressure may also be important in determining the incidence of blast effects.

Indirect trauma. Windows were broken about 20 km. away. The radius of complete collapse of the natives' wooden buildings was around 2.4 km., almost symmetrically distributed about the center. The incidence of mechanical injury was about 60 percent between 500 and 1,250 meters. It was only beyond 2,700 meters that the incidence of mechanical injury in the survivors began to fall off rapidly, but even at about 4,500 meters it was 14 percent. Fatal injuries, however, were almost entirely in the zone of complete destruction. Those indoors in heavy buildings showed a higher incidence of injury than those remaining in native Japanese buildings, because the concrete buildings had more glass windows than those of the native type. This ratio of injury applied only to nonfatal injuries in survivors. It is assumed that the total mortality from immediate trauma was higher in the Japanese buildings than in the concrete buildings at the same distance, because over a wide area of impact the Japanese buildings collapsed from blast while the concrete buildings generally retained their structural integrity. Exactly how much of the total mortality was caused by the traumatic factor will never be known, because within one-half hour following the blast both cities were swept by fire before rescue operations could be instituted. Consequently, even though mechanical injury was not directly responsible for death, it probably contributed vitally to the actual mortality. This accounts for the low incidence of severe forms of injury among the survivors.

Types of injury. The distribution of injuries by type in a group of patients at a military hospital was (1) fractures, 11.5 percent; (2) contusions, 53.8 percent; and (3) lacerations, 34.7 percent.

Flying glass was the cause of most lacerated wounds. The fragments were so small that in many cases clothing was sufficient to protect the body. In one case, at 1,000 meters, the patient was struck by glass fragments which, even though they did not penetrate his trousers, struck with sufficient force to pierce the skin of the upper portion of the bared torso.

BURNS

The burns that occurred may be classified as (1) flash burns, which are the result of the direct action of radiant energy, and (2) flame burns. The latter were relatively rare, for the reason that it took some time, perhaps one hour as stated above, for the fires that were started following the blast to spread within the city. Consequently, those who did not escape were burned to death.

The radiant energy covered the entire width of the spectrum, which resembled that of the sun. Let us now consider only the ultraviolet, visible light, and infrared rays. None of these has a high degree of penetration, so that any solid object, such as clothing or foliage, was sufficient to produce a shadowing effect. Only surfaces exposed direct to the rays were affected by them, and as a result "profile" burns were common. The wood of dark-colored telephone poles was superficially carbonized at about 3,000 meters from the center. A temperature of 4,000° C. acting for 0.5 second is necessary to produce a second-degree burn. It appears that the injurious agents causing flash burns were of extreme intensity but of very short duration.

Burns were remarkably common among those indoors, as it was summer and many of the windows were open. Burns were of no significance beyond 4,000 meters. Beyond 3,000 meters few burns required treatment. Of the deaths attributed to burns, 53 percent occurred within the first week and 75 percent within two weeks. Symptoms associated with the burns varied from case to case but tended to follow a fairly definite pattern. In individuals close to the blast, both burns and blisters were apparent in five minutes. In the vicinity of 1,500 meters, burns appeared in two hours and the blisters in four to six hours. Within about 2,000 meters, the burns appeared in about three hours and blisters after ten hours. In one patient at approximately 2,000 meters, however, there was vesiculation within ten minutes.

Effects of radiant energy on the eye. Direct injuries to the eye were remarkably few. Only a few palpebral burns were noted. The shadowing effects of the supra-orbital ridges and the blink reflex help to explain this finding. Almost all of the patients had temporary amblyopia that lasted for an average of five minutes. A few patients had conjunctivitis and keratitis. Only one patient with a permanent scotoma from perforation of the macula lutea was reported. Two patients suffered traumatic cataract following contusions of the eyeball. A slight reduction in the transparency of the cornea was observed in some, but they presented no subjective difficulties. One patient was so blinded by the flash that he was unable to distinguish light from dark for two days, but he made a complete recovery.

Keloid changes. Keloid changes appeared frequently and in many cases were extreme. According to Japanese physicians, a high incidence of keloids is not characteristic of their race, and they attributed it to the extreme temperature. It has been noted, however, that where skin flaps were removed for plastic surgery, healing resulted in keloid changes. Follow-up studies of this problem are being made by the National Research Council Committee on Atomic Casualties.

Pigmentation and depigmentation. Among the striking features of burns were the changes in pigmentation. At a distance of about 2,000 meters beyond center, the pigmentation, due to ultraviolet rays, was extreme and resembled a walnut stain, the "mask of Hiroshima." These burns were preceded by an intense erythema, which within a few days became increasingly pigmented. Surrounding the hyperpigmented area, a sharp border was seen in which was found a zone where there was even less than normal pigment. This zone represented an area where some melanophores had left to enter the hyperpigmented tissue. This pigmentation began to fade only in a few cases at four months and in many cases still persists. Depigmentation of the exposed skin caused by total destruction of pigment occurred at distances less than 2,000 meters. It was not necessarily associated with scarring of the skin. There was histologic evidence of loss of pigment in the basal layers, even though the epithelium of the surface was not destroyed. At the margins of the depigmented zones there was found a narrow band of increased pigmentation external to which there was a vaguely defined depigmented border as described above. In the area of depigmentation the arrectores pilorum muscles were not damaged, since there was gooseflesh in these areas to the same extent as in the completely undamaged skin.

Etiology of the burns. Certain features of the burns suggest the action of specific wave lengths, probably in the ultraviolet range. The intensity of the pigmentation at about 2,000 meters and, closer to the blast, the extreme depigmentation without destruction of the skin were certainly unusual results of thermal injury. It must be remembered that a relatively small quantity of air intervened between the patients and the bomb in comparison with the entire atmosphere and stratosphere that filter much of the ultraviolet from the sun. Gamma rays were not responsible for the sharply outlined pigmentary phenomena that have been described, since clothing would be no barrier to their action.

Protective effect of clothing. Clothing exerted a protective effect depending on a series of interrelated factors, including: (1) Distance. A khaki uniform, coat, and shirt worn together were protective beyond 1,500 meters. Closer to the bomb,

clothes were no protection. In some instances clothing actually caught fire and the resultant flame burns were among the most severe that were encountered. (2) Color and shade. Darker shades absorb more heat than lighter shades. The effect of selected absorption in many cases was remarkable. At about 1,600 meters, in the case of a white rayon shirt with a pattern of dark blue polka dots, 2 mm. in thickness and 1 cm. apart, the polka dots were burned in the line of the rays, but the intervening white material was undamaged. Extremely interesting was the effect on cotton cloth with flower pattern in a light pink background. The flowers were dark red roses with leaves of varying shades of green. Some of the flowers were entirely burned out, others showed only scorching of the darker portions of the leaves and petals, while the intervening material showed no effects. (3) Tightness. Where the clothing was more tightly stretched over the scapular and deltoid regions, burns were much more likely to occur. (4) Thickness and number of layers. The seams and double layer of the folded over collar demonstrated the protective effect of the thickness of clothing.

RADIATION INJURY

Skin. Epilation was frequently observed in persons who had been close to the bomb and who had survived for more than 2 weeks. At about 500 meters the incidence was about 75 percent and fell off sharply at about 1,250 meters. The time of the onset of epilation reached a very sharp peak between the thirteenth and fourteenth days after the bombing. The hair suddenly began to fall out in bunches on combing or general plucking, or it was found in considerable quantities on the pillow in the morning. This process continued for one or two weeks and then ceased. In most cases the distribution was that of an ordinary baldness, involving first the frontal and then the parietal and occipital regions, and sparing the temporal regions and the scruff of the neck. The eyebrows and even more so the eyelashes and beard were relatively resistent. In one group of patients coming to autopsy, 48 had epilation of the head, 8 of the axilla, 6 of the pubic region, 4 of the eyebrows, and 2 of the beard. Complete epilation is not necessarily correlated with a bad prognosis. Of all individuals who died of radiation effect at about the fourth week fourteen percent had no epilation. It can be assumed that they had received some shielding from concrete buildings or other sources, thereby filtering out the softer rays, and that death resulted from the hard penetrating rays that have little effect on the skin. Even in severe cases, the hair had begun to return by the middle of October and two or three months later had fully returned. In no case reported was epilation permanent.

Gastrointestinal tract. In many patients, severe nausea and vomiting occurred as early as thirty minutes following the detonation. In others it did not occur until the next day. Thirty-two percent of those within a radius of about 1,000 meters and 23 percent at a distance of around 1,100 to 1,500 meters suffered from vomiting on the day of the bombing. The incidence fell sharply to 6 percent at around 2,000 meters. In many patients diarrhea, sometimes sanguineous, occurred within the first few days.

Testes. Histologically, radiation effects on the testes were discernible as early as the fourth day and were profound in all fatal cases in individuals who had been within about 1,500 meters of the bomb. Only three of the 23 patients studied who had been within 1,500 meters had a sperm count in excess of 40,000 (lower limit of normal). Of 39 who had been within 2 km., 13 had counts below 40,000. It is unusual for pregnancy to occur if the sperm count is below 40,000. Several of the patients complained of a loss of libido or even loss of potency following the bombing. According to Japanese physicians the return to normal has been slower in the male than in the female.

Ovaries. Histologically, the ovaries showed less striking changes t an the testes. During the war years in Japan, there was a high incidence of amenorrhea, increasing from 4.3 percent in 1932 to 12 percent in 1944. In 1944, the incidence among 316

nurses of the Tokyo University was 13.3 percent. According to Japanese gynecologists, this was due to malnutrition, overwork, and anxiety associated with bombing. Thirty-six percent of the women in Hiroshima and 29 percent of the women in Nagasaki, between the ages of 15 and 49, who were within a distance of about 5,000 meters, experienced menstrual disorders. The majority of these had one normal period following the bomb and had cessation for an average of three to four months. A year later no patients were found complaining of menstrual disorders attributable to the bombing.

Purpura. In the skin, purpura was almost always manifested in patients dying in the third to sixth week, inclusive. Its incidence at various distances from the blast center ran almost exactly parallel to that of epilation and fell off sharply beyond 1,250 meters. Purpuric spots appeared at about the same time as fever. Their peak was between the sixteenth and twenty-second day, about five days later than the peak of epilation. Associated with their onset, there was an increased tendency to bleed from lacerations, fractures, and burns. Healing of wounds was prolonged, coincident with the appearance of radiation sickness. The growth of granulation tissue stopped, and no tendency to heal was shown. In those who survived, the granulation tissue improved following recovery from radiation sickness associated with the purpuric spots on the skin. After the onset of the purpura of the skin, hemorrhages were also found in the gingivae and from the rectum, nose, urinary tract, and respiratory passages in that order of frequency. The lungs were frequently involved in a necrotizing and hemorrhagic process.

CLINICAL SYNDROME IN RADIATION SICKNESS

Patients who died within the first two weeks. In this group there was histologic evidence of radiation effects on the skin, gastrointestinal tract, lymphoid tissue, bone marrow, or gonads, but these have not been clinically manifested. There was no epilation or purpura. Patients complained of nausea and vomiting on the first day of the bombing, followed by anorexia, malaise, severe diarrhea, thirst, and fever. Death in delirium ensued. Profound leukopenia was present. Temperature records in all these patients were remarkably similar. Usually between the fifth and seventh days, and sometimes as early as the third day, there was a steplike rise in temperature, usually continuing to the day of death. The earlier the fever, the more severe the symptoms and the poorer the prognosis. The bloody diarrhea resembled that of bacillary dysentery.

Patients dying the third, fourth, fifth, and sixth weeks or surviving severe symptoms. In this group, the anatomic and clinical results of radiation attained their acme. Epilation and phyoplasia of the bone marrow were marked. The hemorrhagic and necrotizing lesions were comparable to those seen in aplastic anemia and agranulocytosis, and occurred in the gums and respiratory and gastrointestinal tracts. Petechiae of the skin were almost always present. The sequence of symptoms was as follows: In a typical severe case, the first evidence of the disease was nausea and vomiting on the day of the bombing, followed by a feeling of malaise. The patient then began to improve and felt fairly well until about the beginning of the second week when epilation began. A few days later he again experienced malaise and a steplike fever developed. At about the same time pharyngeal pain frequently appeared. Sanguineous diarrhea was a prominent symptom. The leukocytes and platelets reached very low levels, and a profound anemia was present.

In a third group in whom the bone marrow failed to recover, the symptoms described in the second group continued, and the patients died of extreme emaciation after a prolonged illness. In others, concomitant with partial or complete recovery of the marrow, most of the striking manifestations classed as anemia disappeared, but they succumbed to such complications as lung abscess and tuberculosis.

IV. Evaluation of the Five Atomic Explosions

Employment of the bomb. The atomic bomb is primarily a strategic weapon, and the choice of target and method of employment require the evaluation of a number of factors. Thus far, five atomic bombs have been detonated, three of them under test conditions. The one factor that makes an atomic bomb detonation different from the detonation of any other type of weapon is the nuclear radiation produced. All high-explosive weapons produce high temperature and high blast pressure, and the only difference in these respects between atomic and conventional weapons is the increased magnitude of the blast and thermal effect produced by the atomic bomb. However, no other weapon devised to date is capable of releasing nuclear radiation.

The first bomb was set off under experimental conditions from a tower near Alamogordo, New Mexico, on 16 July 1945. The second bomb was dropped, 6 August 1945, on the city of Hiroshima from a B–29 bomber. Over 4 square miles of the city were instantly and completely devastated; 66,000 people were dead or missing and 69,000 were injured. On 9 August another B–29 dropped an atomic bomb on Nagasaki, totally destroying 1.5 square miles of the city. The number of persons dead and missing in Nagasaki was 39,000, and 25,000 more were injured. The fourth atomic bomb was dropped by a B–29 on target vessels assembled in Bikini lagoon on 1 July 1946, and the fifth was detonated underwater on 25 July 1946. Test animals placed in various locations on the target vessels yielded important data on the bomb effects. This work was under the supervision of the Naval Medical Research Center.

Action of the bomb. When a mass of fissionable material equal to or greater than a critical size is assembled, a violent detonation will occur. The subcritical masses of fissionable material must be brought together rapidly in such a manner that a chain reaction and detonation will occur. The bombardment of each fissionable nucleus by neutrons results in the formation of two fragments known as fission products. All nuclei do not split into the two types of fragment; therefore, many radioactive substances (fission products) are liberated. The sum of the masses of these fission products will not equal the original mass of the split nuclei. The difference between the fission products formed and the original mass represents the mass of the nuclei that has been converted into energy in the form of blast, heat, light, x-rays, gamma rays, and released nuclear particles.

The detonation of the atomic bomb generates a crushing wave of high pressure. The bomb also liberates an enormous quantity of electromagnetic radiations and neutrons. The electromagnetic radiations include infrared, visible light, ultraviolet, x-ray, and gamma radiation. Thereafter, the fission products formed emit gamma rays and beta particles. The unfissioned bomb residue emits alpha particles. Substances bombarded by neutrons released at detonation, which become radioactive by induced radioactivity, may also emit nuclear particles and gamma rays. A large fraction of the gamma rays is emitted in the first flash of the atomic explosion. Neutrons also accompany this reaction. The range of neutrons is negligible at 1,000 yd. because of their absorption in the air. In an underwater burst, greater absorption occurs, resulting in induced radioactivity of the sea water. Of the constituents of sea water, only sodium is of any significance, and even this element is hazardous for only a limited period because of its short half-life (14.8 hours).

At detonation, practically all of the lethal gamma radiation is released, and the remaining small fraction of the total dose is given off by the resultant fission products that rise rapidly in the bomb cloud. The column of radiating fission products and combustion material rapidly rises into the air and begins to mushroom out when

the temperature of the column is equal to the temperature of the surrounding atmosphere. The climatic and meteorologic conditions will govern the diffusion, dispersion, and radiation activity of the cloud. The fissioned and unfissioned material in an airburst will be distributed in the atmosphere; while in a subsurface waterburst, the adjacent water, ships, and land facilities in proximity to the detonation will be seriously contaminated. Fission products in the cloud may be dispersed as fine particles of varying size, and, depending on many factors, a shower of the radioactive material will fall on nearby areas. The fission products, therefore, present a continuing health hazard for a considerable time as an aftermath of the explosion. In general, regardless of the technique of bomb detonation, radioactive materials emitting alpha and beta particles and gamma rays will be encountered. The radioactivity of these substances will range from a few seconds to years. Violent changes in temperature, strong magnetic or electric fields, and drastic chemical interactions have no effect on the rate of transformation or emission characteristics of the radioactive substance. If an element is radioactive, it will decay normally according to its inherent half-life.

In the underwater detonation of the bomb, thousands of tons of water rise in a column, a few thousand feet in the air, followed immediately by a rapidly moving mass of water, constituting the base surge. The turbulent waters contain a high percentage of the fission products and unfissioned residue. Immediately at detonation and for a short period thereafter an enormous amount of radiation is emitted. The falling column of water and mist, depending on wind conditions and depth of detonation, contains a high percentage of the fission products and unfissioned residue that can contaminate an area of several square miles for a considerable period.

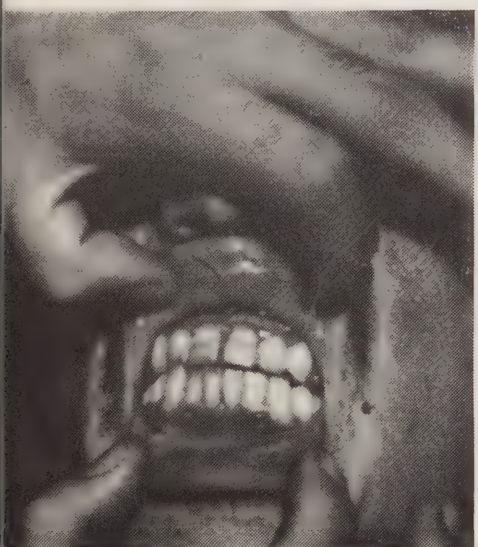
The emission of infrared, visible, and ultraviolet light occurs a few milliseconds after the explosion. The ball of fire in the airburst grows rapidly in size. As it grows, its temperature and brightness decrease. Several milliseconds after the initiation of the explosion, the brightness of the ball of fire is several times the brightness of the sun. Most of the infrared and ultraviolet radiation is given off after the point of maximum intensity. The ball of fire rapidly expands from the size of the bomb to a radius of several hundred feet at one second after the explosion. Thus, the infrared and ultraviolet radiation comes in two bursts—an extremely intense one lasting a fraction of a millisecond and a less intense one of much longer duration lasting several seconds.

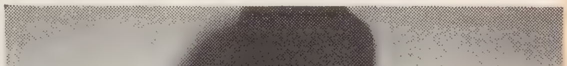
The heat from the flash in an airburst occurs in a short time, and, since there is no time for any cooling to take place, the temperature of a person's skin can be raised 50° C. by the flash of infrared and ultraviolet rays in the first millisecond at a distance of over 4,000 yards. People may be injured by flash burns at even greater distances. Gamma radiation danger does not extend nearly so far, and the neutron danger zone is still more limited. High skin temperatures result from the first flash of high intensity infrared and ultraviolet and are probably as significant for injuries as the total doses that come mainly from the second, more sustained, ball of fire.

Effectiveness against personnel. For personnel in the open, within one-half mile of zeropoint of the airburst detonation, death would occur almost instantaneously or within a few hours from the blast, heat, and radiation effects. Within a radius of one-half mile and one mile from zeropoint, some persons would die instantly, while a majority would receive varying degrees of injury. Ordinary houses and structures would suffer complete destruction or extensive damage and fires would be widespread. Outside a radius of one mile and within a radius of two miles from zeropoint, personnel would suffer injuries from flash burns and indirect blast effects. Outside a radius of two miles and within a radius of four miles, personnel would be injured by flying fragments and suffer superficial wounds. Structures would be half or partially destroyed within this radius. In an airburst explosion 70 percent of those exposed would suffer from trauma, 65 percent from burns, and over 35 percent from radiation.

Flash burns. Formation of keloids. Copper-red tissue at center. Dark red-brown, hyper-pigmented zones at margin

Hemorrhage and ulceration of gums





Flash burns, early stage. (From Japanese hospital records.)

The radiologic hazard. In general, any radioactivity that remains in the area as fission products or induced radioisotopes will constitute a hazard. Fission products from the airburst bomb may be dispersed in the ground or spread out over wide and diffuse areas, depending on the technique employed in the detonation. Consequently, the degree and extent of residual radioactivity would depend on the height of detonation, climatic and meteorologic conditions conducive to the showering of the products on a specific area, and the nature and composition of the terrain. For example, because of the height of the detonation, certain prescribed areas of the bomb crater might remain hazardous. Also, because of the composition of the ground, dust particles intermixed with fission products might rise in the cloud. Many of these "dust particles" might also become radioactive as a result of neutron bombardment released at detonation and thus contribute to the hazard.

When the bomb is detonated over a modern city that contains countless thousands of items composed of iron, zinc, copper, and other "neutron capture materials," it is possible that many of the elements within the effective neutron range may become radioactive for a considerable period. The half-lives of some of these common elements and the radiations emitted are listed in table I. Therefore, objects or material that might survive the detonation, such as medical supplies containing sulfur or arsenic, should be handled with caution until the degree and extent of the induced radioactivity is determined. In some cases, it is possible that fission products also are present and are adhering to the material. In an underwater burst the main hazard, following detonation, will be the result of the deposition of a large percent of the fission products in the water and on nearby objects. In addition, radioactive sodium is formed by the action of neutrons on the sea water. Some of the more persistent and hazardous fission producers of U-235 are listed in table II.

The radiologic hazard can be divided into two phases. The first phase includes the immediate or prompt release of any ionizing particles or radiations caused by the explosion during the period of visible flash of the bomb. These prompt ionizing radiations include beta particles, neutrons, x-rays, gamma and alpha particles from unfissioned bomb residue, and the ionizing radiations from fission products. After the flash of the bomb has subsided, a matter of a few seconds, the delayed phase of the radiologic hazard is of importance. The hazard here is from fissioned and unfissioned material and from radioactive elements induced by neutrons from the explosion. The nature and persistency of the second phase depends on the technique of detonation. In addition to the phase of the radiologic hazard, the protection problem depends on whether the radiation concerned is external or internal to the body. Alpha particles, for example, present no external hazard; but if they are inhaled and become fixed in the bone, depending on the amount, the results may be lethal. Although very little can be done to protect personnel in the open within the lethal range at the instant of detonation, a few points in connection with the second phase may be useful. A comparison of radiations is given in table III.

The relative protection against gamma radiation by shielding, in order of effectiveness, is given by lead, iron, concrete, earth, water, and air. Using the gamma radiation from radium as an illustration, a 5 in. thickness of concrete gives about the same protection as a 1 in. layer of lead. Where no shielding is available, "distance" is the best means of protection. It should be noted that neutrons pass through lead with extreme ease, but are readily absorbed by hydrogenous materials and boron.

The flash burn. At detonation, the flash burns from infrared and ultrared caused a higher percent of casualties than the radiologic effect, because of the increased range of the flash. Light shades of loosely fitting clothing, antiflash cream, and protection of the entire body surface will reduce the percent of casualties. Protection by these means will not reduce the effects of burns produced by secondary fires in buildings or facilities. The problem here is to minimize the amount of inflammable material as far as practicable. In this connection, materials that ignite easily should

TABLE I

Partial list of some common radioisotopes that may be produced by neutrons released at detonation

Radioisotope	Half-life	Radiation
Sodium–24	14.8 hours	Beta, gamma.
Sulfur–35	87.1 days	Beta.
Calcium–45	180 days	Beta, gamma.
Iron–59	47 days	Beta, gamma.
Cobalt–60	5.3 years	Beta, gamma.
Copper–64	12.8 hours	Beta.
Arsenic–74	16 days	Beta, gamma.
Gold–199	3.3 days	Beta, gamma.

TABLE II

*Partial list of fission products of U–235**

Fission product	*Half-life*	Radiation
Strontium–89	53 days	Beta.
Strontium–90	25 years	Beta.
Yttrium–91	57 days	Beta.
Zirconium–95	65 days	Beta, gamma.
Columbium–95	35 days	Beta, gamma.
Ruthenium–103	42 days	Beta, gamma.
Ruthenium–106	1 year	Beta.
Cadmium–115	44 days	Beta, gamma.
Cesium–137	33 years	Beta, gamma.
Barium–140	12.8 days	Beta, gamma.
Cerium–141	28 days	Beta, gamma.
Cerium–144	275 days	Beta.
Neodymium–147	11 days	Beta, gamma.
Europium–155	2 years	Beta, gamma.

*Nuclei Formed in Fission: Decay Characteristics, Fission Yields, and Chain Relationships, survey prepared by J. M. Siegel et al., J. Am. Chem. Soc., 68:2411–2442, Nov. 1946.

TABLE III

Comparison of radiations

Nature	Description	Range		Ionizing power*
		Air	Tissue	
		Ft.	*Cm.*	
Alpha	Helium nucleus (2 protons and 2 neutrons).	0.1	0.01	10,000
Beta	Electron emitted from nucleus	10	1.0	100
Gamma	Electromagnetic radiation from nucleus.	1,000	10.0	1

*NOTE: For each ion pair formed by a gamma ray, 10,000 ion pairs are formed by an alpha particle.

be avoided in the design of equipment intended for military operations. Flash burn is not a serious factor in an underwater detonation.

SUMMARY

Air-burst atomic bombs will produce lethal effects over an area of two square miles and measurable effect over an area of seven square miles as a result of the prompt gamma radiation emitted at the time of detonation. The residual radioactivity is of little importance except in the area close to the center of a low-altitude explosion. In an underwater detonation, radioactive fission products and unfissioned material will be spread by the cloud and base surge over a large area. The gamma radiation from these materials will be lethal to exposed personnel more than two miles downwind, and serious contamination will result at much greater distances. This contamination will provide a serious hazard for an indefinite period. Prompt evasive action at the time of the detonation will permit the reduction of casualties, and orderly evacuation and re-entry procedures will undoubtedly pay great dividends in minimizing the effects.

V. Fundamentals of Radiation Pathology

The pathologic effects of radiation can best be presented by outlining the early and late changes in (1) tissue cells, (2) organ systems, (3) total body irradiation, and (4) internal radiation by radioactive materials introduced into the body either accidentally or therapeutically. Sensitivity of the various body tissues has been well established, and has been expressed largely as the relation of one tissue to another. Table I shows the relative sensitivities as indicated in two studies.

TABLE I

Relative radiosensitivities of various body tissues listed in decreasing order

Desjardins*	Warren**
Lymphocytes	Lymphocytes and (germ cells).
Granulocytes	Granulocytes.
Epithelial cells	Epithelium.
(a) Basal cells of secretory glands.	Smooth muscle.
(b) Basal cells of testes and ovarian follicles	Fibroblasts and derivatives.
(c) Basal cells of skin and gastrointestinal tract	Neurons.
(d) Alveolar cells of lungs; bile ducts	
(e) Tubules of kidneys	
Endothelial cells	
Connective tissue	
Muscle cells	
Bone cells	
Nerve cells	

*Desjardins, A. U.: The Radiosensitiveness of Cells and Tissues and Some Medical Implications, Arch. Surg., 25:926–492, Nov. 1932.
**Warren, S.: Histopathology of Radiation Lesions, Physiol Rev., 24:225–238, Apr. 1944.

Reactivity of the tissues in terms of energy or actual ionizing effect from a quantitative standpoint is somewhat less definite. Variation in response to ionizing radiation has been indicated in numerous studies, but becomes of particular interest in total body radiation, since in this circumstance the variation is not only a question of

death or survival over a relatively broad range of radiation dosage, but also manifests itself as well by variations in organ responses, presumably by an equally wide range in symptoms and clinical findings. The effects of ionizing radiation are considered at present to be similar for all types of radiation—alpha, beta, gamma, x-ray, and neutron sources—when equal amounts from the standpoint of energy and time relationship are absorbed in the tissues.

Tissue cells. There is no satisfactory indication of any tissue effect of radiation other than destruction. In prolonged exposures of animals to tolerance and slightly higher levels, survival rates were higher in the exposed groups than in the controls. This same tendency was noted in weight curves. The exposed animals showed weights consistently above those of the controls, mostly from abdominal fat. This was considered not to be a castration effect. From a morphologic standpoint, however, the purely destructive effect has been emphasized in a recent report by Bloom.[1] It is well to keep in mind that it is unlikely that all tissue has been subjected to the ionizing action of radiation. Microscopically, any one or all of a number of cellular changes may be observed, such as: (1) changes in staining characteristics, usually an increase in eosinophilic properties; (2) increased granularity, usually of cytoplasm; (3) vacuolation of a variable degree; (4) swelling of cellular components; (5) distortion of cellular structures; (6) cytolysis (loss of definitive borders); (7) pyknosis; (8) changes in Golgi's apparatus; (9) reduction in mitotic activity; (10) production of abnormal mitoses; (11) chromosomal changes (fragmentation, clumping); and (12) increased refractile neutral red staining bodies within leukocytes seen by vital staining methods. These changes are found in conditions other than radiation, and although highly suggestive are not specific. Alterations in the noncellular tissue may include intercellular edema, swelling and hyalinization of colloid, and swelling and fragmentation of elastic tissue. A more direct approach to the cellular changes is found in observations on cellular viscosity, ciliary action, phagocytosis, cellular secretions, and a few enzyme systems that can be demonstrated. Alterations in these processes have been described following radiation.

Initially no changes may be found. Alterations in viscosity and slightly increased acidophilic staining properties are among the earliest findings. Cessation of mitoses and destruction of lymphocytes may occur in a matter of hours or less. Vascular dilatation and edema may follow, and, in the case of larger doses, actual necrosis of tissue cells may occur, again depending on the relative sensitivity. These represent only the readily demonstrable changes, and are certainly an inadequate and relatively crude index of the tissue alterations.

In small or moderate doses recovery may occur with no residual lesion, may show the frequent pattern of repair by fibrous tissue replacement, or, in other instances, may show the pattern of repair characteristic of the organ. There is no indication that the features of repair are specific or characteristic for any or all types of radiation. References to "radiation fibroblasts" and "radiation dermatitis" lead one to assume that these are peculiar to radiation injury, although such is not the case; but these designations are useful in evaluating tissue damage and probable etiology. The recovery stage in terms of tissue repair is often a matter of months or years and, in the case of repeated or continuing exposure, becomes a much more important problem.

The late effects, in most instances involving repeated exposure to radiation, are well established and include: (1) atrophy and ulceration of the skin, telangiectasia, fibrosis, and vascular occlusion, which were early recognized as radiation effects; (2) carcinoma of the lung, which in the Schneeberg mines was considered to be due to the radioactive material present in the inspired air; (3) bone sarcoma developing in persons ingesting radium; (4) carcinoma of the skin as a late effect of repeated exposure to x-rays; (5) leukemia, which has an increased incidence in those exposed

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[1] Bloom, W.: Histological Changes Following Radiation Exposure, Radiology, 49:344–348, Sept. 1947.

to repeated radiation; and (6) other effects, such as genetic variation and shortening of the life span.

Lymphoid tissue. Changes in the lymph nodes have been described by many investigators. Relatively small doses produce in a short time nuclear degeneration of lymphocytes and some distortion of the germinal centers. Congestion, swelling, and slight inflammatory cellular infiltration may occur. Mitoses are not seen until regeneration becomes active. Continued cellular degeneration is followed by increasing and active phagocytosis by large macrophages. Erythrophagocytosis occurs in addition to the phagocytosis of nuclear and cellular fragments. The inclusion of red blood cells in the macrophages is an early finding, the significance of which is not well understood. Repair following small doses is rapid and apparently complete. Somewhat greater doses result in a marked reduction of lymphocytes, leaving an almost empty reticular stroma with the persistence of a few small lymphocytes and a few larger reticulum-type cells associated with the germinal centers. Repair may take place, if the destruction has not been too great, apparently from the remnants of such centers, often with definite irregularity in the size, shape, and pattern of the lymph node. If the damage has resulted in almost complete destruction, the area may consist of more or less condensed stroma and loose connective tissue containing a few scattered lymphocytes. Such areas are said to offer no resistance to lymphoid circulation.

The spleen is less sensitive than the lymph nodes and regenerates less completely. A similar cycle of changes occurs. Loss of the lymphocytes may result in condensation of the stroma, and an accentuation of the reticular and sinusoidal pattern occurs. Regeneration, if it takes place, may show considerable irregularity in the cellular forms. Phagocytosis is active, and quantities of pigment may be present in the spleen after recovery. As in the lymph nodes, regeneration appears to proceed from the remaining recticulo-endothelial elements. The heavy accumulations of pigment have been interpreted as evidence of excessive blood destruction, or failure of splenic tissue to dispose of the material, or both. The thymus shows changes of a similar nature, although phagocytosis and disposition of pigment are not seen as in lymph nodes and spleen.

Bone marrow is more resistant to radiation than lymphoid tissue. Destruction of cells appears to involve both the immature granulocytic and erythrogenic forms. Regenerative changes are seen early, within the first week. Pigment deposits, eosinophils, and plasma cells may appear. With particularly heavy irradiation, almost complete loss of cellular elements may occur, with only a few reticulum cells and perhaps an occasional focus of erythropoietic cells. The marrow in such cases possesses a peculiar gelatinous appearance, grossly, with a deceptive red coloration arising from red blood cells within dilated vessels or dispersed extravascularly. Such marrow may regenerate adequately, or may result in an aplastic marrow with variable amounts of connective tissue. In the case of ingested radioactive material, any stage of hyperplasia or aplasia may be found, depending on intensity and distribution.

The peripheral blood picture does not indicate in adequate fashion the processes occurring in the marrow. For example, the apparent paradox occurs in which a hyperplastic marrow is present with a relatively low count in the peripheral blood, which is found in conditions other than radiation effect. In these cases there is usually some lack of maturation within the marrow. This introduces the question that has been asked a number of times in the literature: What factors determine whether a given hematopoietic system, when subjected to repeated demands, stimulation, or insults, will respond by hyperplasia or aplasia? Warren cites the histories of two chemists working with radioactive substances over a period of years in the same laboratory. They observed no protective measures and died within five days of each other—one of aplastic anemia, the other of myelogenous leukemia. One can observe such cases clinically and encounter stages at which one is unable to indicate whether the case will progress to leukemia or to an aplastic anemia. Again this is

not a situation peculiar to patients exposed to irradiation. Several well-known characteristics of radiation are shown by the marrow. One is the destructive effect on tissues elsewhere in the body, when exposure is limited to a relatively small area. Another is the cumulative action of radiation. In successive exposures, the radiation necessary to show definite effects becomes less, and the periods necessary for recovery become longer. This has been expressed in the term "percentage recovery" for certain exposure.

Gonads. The reaction of the cellular elements of the seminiferous tubules to radiation varies. There is evidence to indicate that the primary spermatocytes are the more sensitive, contrary to the general statement that more primitive cells are more sensitive. Next in order of disappearance are the spermatogonia, small spermatocytes, spermatids, and spermatozoa, with the Sertoli's cells remaining and proliferating to replace the germinal epithelium. In other instances the spermatogonia, the most immature germinal cells, have been observed to be the only ones persisting. The interstitial cells have been generally regarded as resistant to radiation. The ovaries are less sensitive than the testes. Maturing follicles have been described as the most sensitive portion, and corpora lutea as relatively resistant. In mice, development of ovarian tumors following irradiation in the tolerance levels has been described.

Gastrointestinal tract. Edema and degenerative changes in the epithelial cells occur early. Subsequent changes may include hyperemia, hemorrhage, cellular changes progressing to necrosis, often with a thick superficial fibrin membrane, and subsequent ulceration. Mitotic figures and atypical cellular forms are seen within a week and are considered to be regenerative in nature, although closely resembling degenerated cells. These early epithelial changes in the gastrointestinal tract have been linked with the profound toxic changes. Connective tissue areas of the walls of the gastrointestinal tract show edema and myxomatous and hyaline changes, the same areas often containing bizarre connective tissue cellular forms. Later effects include fibrosis, atrophic changes in the mucosa such as reduction in the number of glands, and in the gastric mucosa a reduced number of chief cells. Ulceration is a relatively frequent occurrence after an extended period.

Respiratory organs. Pulmonary tissue is considered moderately sensitive to irradiation. A transient pneumonitis occurs, without apparent late effect. No significant changes have been described in the bronchial system.

Skin. The essential features include an early erythema occurring within a few hours to a few days, disappearing within a period of days, followed by a second occurrence of erythema ten days to four weeks later. This second episode represents the culminating pathologic change in the connective tissue and vascular bed of the corium, in contrast to the more direct injury to epithelial cells resulting in the early erythema. Pigmentation, epilation, and ulceration may follow with destruction of dermal glandular structures. Atrophy, hyperkeratosis, and telangiectasia may develop after repeated small doses without the preceding clinical manifestations and with the possibility of malignancy. The histologic picture is characteristic. The epithelium is thin, with obliteration of rete pegs. Irregular acanthosis may be present with cellular abnormalities. The corium shows dilated vascular spaces, atrophic skin appendages, dense and hyalinized collagen with variable basophilia, and reduced or absent elastic tissue.

Other organ systems. The epiphyseal region of infants and children is particularly reactive to radiation. In the eye, radioconjunctivitis occurs with moderate doses and may be followed by keratitis. Lenticular opacity occurs in young eye tissues with moderate doses, as compared with the greatly increased doses necessary in mature lenticular structures. Tissues that have not been discussed are generally in the less reactive range and undergo few changes except in massive localized exposure. To this group belong nerves, heart, liver, pancreas, bone, and muscle.

Total body irradiation. Doses used commonly, such as the erythema dose, approach or exceed the lethal dose when applied to the entire body. It is of considerable

interest to define the changes at various levels of total body irradiation, and a certain clinical experience is available, as well as numbers of animal studies. Early and rather striking changes have been described in the gastrointestinal tract of animals dying of total body irradiation, with relatively slight changes elsewhere. Survival for a longer time places the organism in a period in which vascular damage and hemorrhagic phenomena are outstanding. The generalized destruction of hematopoietic tissue is a major factor at this and later stages. The findings at later stages are those of severe infection without adequate cellular response, and presumably without adequate resistance.

Internal radiation by radioactive substances does not involve any differences from the tissue reactions described, other than those associated with localization and intensity. The action of radioactive substances internally depends on (1) the activity of the substance ingested, whether an alpha, beta, or gamma emitter, and the duration of its activity; and (2) behavior in the body—rate of excretion, affinities for certain tissue, and its course of localization. For example, radioactive sodium-24, which is highly diffusible in the body, gives the pathologic picture of total body irradiation from an external source. The localization of many of the radioactive materials in relation to bone has intensified their effect. The lesions in radium poisoning may be used as an example—bone necrosis, particularly in the jaw, destruction of marrow with variable hyperplastic and aplastic changes, and the incidence of malignancy in the form of bone sarcoma. The amount of radioactive isotopes required to produce bone sarcomas, lymphomas, and the like in animals is practically identical with that required to produce perceptible effects in the peripheral blood.

VI. Pathologic Anatomy of Radiation Effects of Atomic Explosion

Before considering the radiation effects on the systems of the body, it is important to consider the relationship of lesions and time of death. In Japanese patients dying within two weeks after exposure there was histologic evidence of radiation in the bone marrow, gonads, gastrointestinal tract, and skin that was not manifested clinically. In the group dying in the third to sixth weeks, bone marrow changes predominated, while neutropenic ulcers and hemorrhagic symptoms were very common. The general nutritional state declined. Gross changes were at the peak. Those dying in the third and fourth months showed beginnings of recovery in bone marrow and hair regeneration. Testicular and connective tissue changes remained evident. There was an increase in the number of emaciated patients. The poor nutrition was not based entirely on shortage of food. Intestinal lesions and other factors played an important part.

Skin. The quickly visible changes in Japanese affected by an atomic bomb were the pigmented areas that appeared in the first few weeks and persisted. These had such sharply demarcated outlines that they were considered as flash burns. Whether very soft, nonpenetrating gamma rays played a role has not been determined. Development of what we have recognized as ionizing ray skin burns was not seen. There were a few early cases of bullous edema that may have been from gamma rays. Epilation appeared mainly on the scalp, occasionally more on one side than the other; in the axilla in 16 percent; in the pubic region in 12 percent; and in the eyebrows in 8 percent.

Microscopically the hair follicles showed distinct changes both in the epidermal and dermal coats. Early specimens were not obtained, but in the fourth week the internal root sheaths could not be identified, the external sheath (continuous with the malphigian layer of the epidermis) being continuous with the hair shaft. Vascularity of the papillae was reduced, and the adjacent epithelium was atrophic. Pigment was irregularly clumped. The dermal coat showed thickening both of the inner hyaline membrane and the cellular fibrous layer. In pushing the base of the

hair toward the surface a continuous shrinking in the bottom of the follicle occurred until regeneration took place with new cells over the papillae in a manner similar to ordinary hair replacement. There was also atrophy of the sebaceous glands, but this was also present when old hairs were replaced in the normal individual.

Some of the sweat glands were small, their cells occasionally vacuolated and pyknotic, and the basal membranes thickened. Evidence of radiation on the skin was not definite. Third degree flash burns could also be expected to have some radiation effect, but interpretation was difficult. At the edge of the burn area there was hyperpigmentation in basal cells and chromatophores. Some thinning of epidermis, hyperkeratosis, ironing out of papillae, and hyperpigmentation of basal cells were found in the scalp. Vascular and collagen changes were minimal.

Pituitary. Large basophilic cells with much cytoplasmic vacuolation appeared in 25 percent of the males dying in the third to sixth weeks. Because cells of this type are found in mammals after castration, they are known as "castration cells." In the second and third months large basophils were found, only a few being vacuolated.

Adrenals. In the first two weeks there was a loss of lipoid in the cortex, but in the next months the cortex progressively lost its orange-yellow color and was distinctly thin. Microscopically, most cells were granular rather than foamy, and the atrophy was most marked in the outer zona glomerulosa, contrary to what was expected. When foam cells were present, they were usually in the inner layer. The medulla was normal.

Heart. Epicardial petechiae were found within the first two weeks, and there was microscopic evidence of some perivascular and rare muscle edema in the myocardium. These changes continued to be present during the second month when myocardial hemorrhages were also seen. After the second month no distinct irradiation changes were found.

Lungs. Only the slight perivascular edema of the pleura that appeared in the first two weeks might be a primary radiation effect. Hemorrhagic and necrotizing pneumonia were common after the first weeks, as secondary lesions.

Genitourinary system. Except for hemorrhagic manifestation, there were no primary lesions in the kidneys and ureters. In the hemorrhagic stage of the radiation disease, mucosal hemorrhages in the bladder might result in necrotizing ulceration without evidence of leukocytic infiltration. The prostate and seminal vesicles were not remarkable, except for a rare neutropenic necrosis and the presence of a few spermatozoa that were morphologically normal in spite of the irradiation.

The testes showed intense changes in almost every cadaver. As early as the fourth day when the parenchyma had a normal appearance grossly, the histologic sections presented marked injury of the germinal epithelium, numerous cells of which were necrotic and free in the tubules and even in the rete testis. The number of mitoses was small. Sertoli's cells were increased in number. Mature spermatozoa were found even in later specimens with no spermatogenesis. Apparently uninjured spermatozoa appeared in the seminal vesicles. In the second month gross examination revealed little. A few necrotic germ cells remained, but most had disappeared, and phagocytic or infiltrating inflammatory cell activity was absent. A few bizarre cells still approximating the basal membrane appeared to be spermatogonia. Sertoli's cells were more numerous. The tubules had started to shrink. At this time also the interstitial cells of Leydig were so prominent that some interpreters considered them hyperplastic. Some of the small interstitial vessels showed the most marked vascular change of any part of the body. Beneath the distinct thin endothelium was an eccentrically located mass of eosinophilic, homogeneous, refractile material that almost occluded the lumen. This change was often best seen near the tunica albuginea and was present also in the third and fourth months. The interstitial tissue was less, but still prominent. The basement membranes were quite thick, wavy, and acellular. The tubules, more atrophic at this stage, were often hyalinized. Elsewhere Sertoli's cells had replaced the germ cells, which were rare. In the third and fourth months

the state of nourishment was poor and specimens from the Dachau prison camp in Germany have been described as showing similar testicular changes.

Changes in the ovaries were much less striking. Gross changes, except as part of the hemorrhagic phenomena, were absent, even to the presence of a well-developed corpus luteum of pregnancy seen about the end of the first month after irradiation. Histologically, primary ova were usually present and only occasional specimens had a few atresic primary follicles. The absence of developing follicles was usual. There were no corpora lutea and the "resting phase" of the endometrium reflected this. Amenorrhea was distinctly increased in Nagasaki, and a significant number of abnormal births and an increased death rate of the mothers in relation to distance from the explosion were found there.

Gastrointestinal tract. This tract was one of the first to show gross lesions. Even before hemorrhagic manifestations the cecum or colon, particularly, might present a widespread change marked by swelling, green and yellow-gray coloration, and induration of the mucosa, sometimes with a pseudomembranous effect, and with much submucosal edema. Later mucosal hemorrhage might institute another cycle of similar change in the stomach or intestine. This change might begin with ulceration of the mucosa at the site of the hemorrhage and progress to a pseudomembrane or deep ulcer. Again, in the third and fourth months an enteritis, usually in the large intestine but sometimes affecting the small intestine and occasionally the stomach, might be the most prominent lesion. In the small intestines only the tips of the folds might first be involved. These looked at first as though they had been dipped in boiling water and then became green or yellow-gray. A few specimens of small intestine had a diffuse mucosal process. The large intestine in this late stage usually had a more widespread process that might extend from the ileocecal valve to the rectum. The thickened wall was characteristic. A pseudomembrane and ulceration were sometimes present so that the morphology was similar to that of bacillary dysentery. Much of the process here was not only an irradiation effect of the sensitive intestine, but also a result of the lowered local ability to cope with intestinal microorganisms and, probably more important, to the lowered antibiotic capabilities of the blood.

Microscopically the epithelium early contained extremely bizarre cells with giant hyperchromatic nuclei and multipolar mitoses. The swelling was seen to be from edema and the peculiar coloration from the absence of infiltrating leukocytes. Later, areas of mucosal ulceration with much fibrin, few lucocytes, and in the remarkably edematous submucosa quite a few histiocytes, a few lymphocytes, and occasional eosinophils were seen. Plasma cells of the lamina propria remained numerous.

Spleen. The lymphoid elements here reacted to radiation as in the nodes. Early spleens were usually small, but occasionally showed the early swelling reaction. On section, they were dark red and firm, the follicles were indistinctly seen, and the trabeculae were prominent. Besides the near absence of lymphocytes, large mononuclear cells were increased, and erythrophagocytosis and hemosiderin deposits were seen. In the second month the spleen was small and follicles were absent. There was a syncytial reticulum around the follicles in which the slight lymphocytic content of the organ was seen. Atypical large mononuclears were found in about 25 percent. Through the fourth month there was still some atrophy. Occasional germinal centers appeared, and the lymphocytic content showed evidence of recovery.

Lymph nodes. The high sensitivity of lymphoid tissue to ionizing radiation resulted in tremendous atrophy seen as early as the third day. Lymphocytes almost disappeared, leaving a lacy framework that was histologically spectacular. A similar picture was found in the tonsils and other lymphoid tissue. Changes in the germinal centers might be necrobiosis, but a departure from normal was not marked except when the germinal centers disappeared, as they did in three-fourths of those who died in the first two weeks. The early gross appearance of human nodes was not known, but bombed animals showed some enlargement, softening,

and a paler color. By the second week large atypical mononuclear cells, considered by one observer as lymphoblasts, appeared. These cells logically could be pathologic forms whose sensitive nuclear chromatin was deformed by the radiation. About the fifth week, the nodes were usually small and almost devoid of lymphocytes and germinal centers. Bizarre large cells were more numerous. Plasma cells, eosinophils, and mast cells, along with increased numbers of reticulum cells, were present. Lymphocytes were more numerous in the fourth month but were still reduced.

Bone marrow. The cellular picture of irradiated bone marrow was tremendously changed in the first week after the bomb explosion. There was almost total disappearance of blood-forming elements, excepting small islands of erythropoiesis, which were less sensitive. By the end of the week reticulum began to proliferate and differentiated first into lymphocytes and plasma cells rather than myeloid cells. This type of differentiation was predominant until the fourth week when myeloid differentiation was seen. Most marrows of those dying before six weeks were hypoplastic, but a few showed hyperplasia with arrest of maturation. Most of the fatal cases of the third and fourth months showed hyperplasia, which in the femur was grossly evident as pink marrow extending through from one-third to one-half of the shaft. In these the maturation defect decreased and more neutrophils were found in the peripheral blood and in infected tissues. A few of the older cases, however, showed aplasia with pink gelatinous femur marrow. Some grossly appearing hyperplastic marrows were really hypoplastic, the pink color coming from dilated blood vessels. Whatever the marrow picture, there was usually a profound leukopenia at some time in those dying in the first six weeks. Later leukopenia did not persist, and even those who died had leukocytosis except for the few that had aplastic marrows.

Miscellaneous. Only secondary hemorrhagic or necrotic changes were found in the brain. No changes were found in the pancreas, except for some mitoses in the islet cells. The presence of any irradiation effects in the liver is a moot point.

Secondary effects of radiation of reticulo-endothelial system. Hemorrhagic lesions and leukopenic necrosis affected the irradiated body about the end of the first month. The pharynx and its connections, the gastrointestinal tract, the respiratory organs, and the skin manifested both changes. In addition, particularly the urinary tract, mesothelial linings, muscles, and all soft tissues, showed petechiae, purpuric patches, or large ecchymoses. These changes were outstanding clinically. The severity depended on the location of the larger hemorrhagic lesions. Hemorrhages in the linings of the pharyngeal regions, of the bowel, or of the urinary tract gave signs externally. Large submucosal hemorrhages as well as petechiae appeared in the kidney pelves and in the bladder and sometimes in the ureters. Hemorrhages breaking through the epithelium of bacteria-laden surfaces often initiated the neutropenic ulcers, which in the pharynx were similar to acute agranulocytosis. Ulcers sometimes extended to the tongue, gums, buccal mucosa, lips, and even the skin to give the picture of noma. Such ulcers also began without hemorrhage. Bacteria ordinarily nonpathogenic might cause serious consequences through the loss of sufficient reticulo-endothelial reserves. Ulcers throughout the gastrointestinal tract were on a similar basis, as indeed, many of the diffuse mucosal changes might be. The necrotizing pneumonia appeared to be a part of this picture. There was little leukocytic reaction in these lesions, which overwhelm the patient and lead to death.

Case history. A 29-year-old man was at a distance of 0.7 km. from the explosion center. He was outdoors a few paces from a concrete building and was struck by a falling roof that inflicted slight head and neck injuries. There was nausea on 6 August 1945, and on the same day he vomited about 25 times. Malaise, accompanied by anorexia, began on 6 August and lasted until 10 August. He again experienced malaise from 21 August until he died on 1 September. Anorexia appeared four days after the second onset of malaise. There was epilation and

gingivitis on 21 August, which persisted. The gingivae began to bleed on 30 August. On 25 August tonsillitis and purpura were noted. Both of these symptoms lasted until death. There was a high fever between 24 August and the time of death; and there was a productive cough beginning on 25 August with a hemoptysis on 30 August. The urine examined on 29 August was positive for albumin and negative for sugar.

Sections of marrow in this patient were hyperplastic, showing vascular adipose tissue crowded by a large number of young myelocytes. Mature polymorphonuclear leucocytes and even stab cells were rare. There was an occasional megakaryocyte. Occasional cells were found in mitosis. A few small cells with shrunken nuclei, thought to be normoblasts, also were found. Other important lesions at necropsy were: petechiae of the skin; epilation of the scalp; focal necrosis of the pharynx, tongue, tonsils, and larynx; necrotizing gingivitis; an abscess in the region of the right mandibular joint; necrotizing and hemorrhagic aplastic pneumonia; and minute hemorrhages of the gastrointestinal tract, trachea, and renal pelvis.

VII. Detection of Overexposure to Ionizing Radiation

At present the potential sources of exposure to radiation include: (1) diagnostic and therapeutic x-ray units, (2) industrial x-ray machines, (3) radium and its degradation products, (4) cyclotrons, (5) the chain reacting pile, (6) radioisotopes produced by the pile that are being used in tracer studies, therapy, and as sources of heavy radiation for biologic systems, and (7) the atomic bomb and its fission products. It is apparent that the medical profession and public health authorities must take cognizance of the sources of exposure and endeavor to establish means of prevention and recognition.

Prevention is accomplished by careful measurement of radiation intensities by personnel film badges and radiation detection instruments whenever radiation may be present. Personnel should be followed closely for the presence of radioactive isotopes in nasal secretions, excreta, and on the skin. Where radioactive gases may exist, expired air should be monitored. In brief, overexposure to radiation should never occur. Since signs and symptoms are late, conditions conducive to excessive exposure should be detected by physical measurements before cellular damage occurs. In spite of this, protective regimens may fail, and in the advent of atomic warfare many will be overexposed to ionizing radiation regardless of precautions. Many earlier scientists learned of the hazards of radiation by tragic personal experience. The incidence of radiation burns, ulcers, and superimposed cancer in the early physicists and radiologists, the incidence of aplastic anemia in x-ray technicians, and the greater incidence of leukemia in radiologists point to the possible hazard of long, continued minimal radiation and potentially harmful cumulative effects.

The effects of overexposure may be acute or chronic. The exposures may result from any type of radiation externally or internally applied. The clinical picture will depend on the amount, rate of delivery, and depth of the dose. Acute overexposure may be defined as a single total body exposure of more than 50 r. delivered within a period of a few hours. The signs and symptoms that may develop vary with the penetrating ability of the radiation and the amount absorbed. If the skin receives a large amount of soft x-ray or beta radiation, anything from a slight erythema to massive vesicle formation and destruction of its full thickness may develop. The injury will resemble thermal burns.

Similar cutaneous injuries can be caused by more penetrating radiations; but, in addition, other signs and symptoms such as diarrhea, nausea, vomiting, headache, anuria, purpura, and secondary infections largely caused by the leukopenia may develop. The latent period before the development of symptoms will vary with and be inversely proportional to the amount of radiation absorbed. The symptoms and signs will be directly proportional to the amount of radiation received up to the

point that the latent period becomes so short that there is insufficient time before death for the entire picture to develop. The signs and symptoms of acute overexposure to penetrating radiation are variable. Although the best biologic index of overexposure to radiation is the blood, with the less penetrating external radiation the blood changes are less marked and may be absent.

The blood changes following acute exposures are fairly uniform if the exposure is over 100 r. The changes with smaller amounts of radiation may be missed if careful and repeated observations are not made at frequent intervals. There is, however, a uniform response to amounts over 100 r. that is roughly proportional to the amount received, up to a maximum response in the absolutely fatal dose range. The response is a prompt decrease in the total lymphocyte count that is detectable within a period of a few hours. The decrease attains a maximum within about seventy-two hours. Recovery may or may not occur, depending on the amount received. Another quite constant phenomenon is an initial neutrophilic leukocytosis caused by mobilization of the neutrophils and perhaps accelerated maturation and release from the bone marrow. It is reported by some workers that the leukocytosis does not occur with massive amounts of total body radiation (over 500 r.) in some species. The changes in the numbers of platelets and red blood cells and morphologic changes of the leukocytes are less certain and vary so much with the dose and the survival time that they will not be considered here. The acute blood changes can be summarized as follows: If no drop in the total lymphocytes is detectable in the first seventy-two hours, it can be stated with certainty that the exposure to radiation has been small and that serious illness will almost assuredly not occur.

The chronic overexposure to ionizing radiations presents an entirely different problem. The changes that occur are insidious and progressive. In fluoroscopists, radiochemists, or radium handlers the following may develop on the hands: (1) an increased brittleness and tendency to develop longitudinal ridges of the fingernails, (2) loss of integrity of the fingerprint by patches of atrophy, (3) impaired sensation, and (4) pigmentation. In general, as with the acute exposure, the blood is the best biologic index of overexposure to radiations. In order to evaluate the blood picture, some sort of norm for the average person must be established. This is most difficult, for the human blood is variable. Leukocyte counts of 4,000 to 16,000 are occasionally found in people who are in every other detectable respect perfectly healthy. The differential counts vary considerably with age and may remain abnormal for many months following infectious mononucleosis. Erythrocyte counts and hematocrit and hemoglobin determinations similarly vary widely. The time-honored normal values for hematological measurements probably include 80 percent of a given population within the upper and lower limits of the ranges given in standard textbooks. The 20 percent of normal individuals outside of this range will cause considerable consternation in a radiologic safety program.

How are blood changes that may be caused by chronic overexposure determined? First, base line counts should be established on all who may conceivably be exposed. The counts should be made at monthly intervals. Notations on the occurrence of colds, infections, and other symptoms should parallel the blood records. Relative changes in the blood of a given individual may then more readily be detected. The following hematological criteria for presumptive evidence of overexposure to radiation are offered and have been based on standard normal values and possible changes that have been described in the literature: (1) a depression of the leukocyte count below 4,000; (2) an elevation above 15,000 with an absolute and relative lymphocytosis; (3) a relative lymphocytosis with a low total count that returns to normal following removal from exposure; (4) an increased mean corpuscular volume, a shift in Price-Jones curve to the right, and an increase in the mean corpuscular diameter; (5) a reticulocytosis over 2 percent; and (6) an erythrocyte count over 5.1 million/cu. mm. and hemoglobin over 18.0 gm. percent. If any of the above criteria develop in a person who has a definitely established base line and who is

associated with radiation, it is presumptive evidence of overexposure to radiation until proved otherwise.

Many other phenomena have been suggested as hematological evidence of overexposure. Changes in blood coagulation, prothrombin times, platelets, and morphologic changes in leukocytes, such as toxic granules, basophilic staining, and vacuoles (the toxic triad), have all been offered. It is exceedingly difficult to evaluate the importance and the diagnostic value of those changes. The evaluation of chronic exposure of any given individual in terms of changes within the blood cannot be made with absolute certainty. The following procedure may yield helpful information: (1) Remove the suspect from all possible sources of radiation. (2) Study breath, excreta, and nasal swabs for the presence of radioactive isotopes by making differential radiation counts. (3) Study the blood at weekly intervals and compare with the base line counts. (4) Endeavor to eliminate other factors, such as infectious mononucleosis, infectious lymphocytosis, virus diseases, benzol poisoning, and heavy metal poisoning. (5) Examine others that may have been similarly exposed and compare the base line mean leukocyte counts with the present mean counts for the group.

The fifth maneuver may yield more information than all the other blood changes combined. If a statistically significant difference in the means of the leukocyte counts of a group of people can be demonstrated during known chronic exposure as compared to the base line means, particularly if the difference shows a downward trend, it can be stated with some assurance that there has been chronic overexposure to radiation. The development of the above presumptive signs in the mean leukocyte counts for a group must be considered as evidence of overexposure until proved otherwise. The main bulwark of protection from radiation must remain physical control and measurement by established monitoring procedures.

VIII. Public Health Aspects of Atomic Explosion

It is hard to think of a group as other than made up of individuals. It is equally difficult to regard the individual without giving some consideration to the fact that he is a member of society. Public health is that branch of medicine that deals with the relationship of the individual to the community and of the community to the individual. At present the emphasis is shifting from the absence of disease to the presence of health.

In the event of an atomic explosion the medical officer will be called on to assess the hazard and to advise the command accordingly. He will probably have the necessary physical findings supplied to him. The magnitude of the hazard will depend on many factors. The advice of not only the physicist but also the meteorologist, geologist, and oceanographer will be needed. In damp or rainy weather there is little dust, therefore ground contamination will not be as serious from an internal (inhalation) standpoint as it would be under dry conditions. In assessing the hazard, it must be kept in mind that external radiation is more easily dealt with than internal radiation. You can guard against external radiation, but you must prevent internal radiation. Decontamination of the skin, although at times difficult, is far easier than decontamination of the thyroid, lungs, or bone.

The common personnel monitoring devices are film meters, pocket ionization chambers, pocket electroscopes, and Geiger-Müller tubes. Area monitoring instruments include Geiger-Müller tubes, electroscopes, ionization chambers, film meters, and dust- or air-sampling devices. Let us assume that an area is contaminated. It may be contaminated with: (1) Alpha emitters. This will constitute a most serious hazard if such substances gain access to the interior of the body. There will be no external radiation hazard. (2) Beta emitters. This will constitute both external and internal radiation hazard, which is more serious per unit if internal. (3) Gamma emitters. Here again we must think of both external and internal hazard, which is more serious from a practical standpoint if external. (4) Contamination. Con-

tamination will almost certainly not be limited to one of the above types of radiation.

Food. It must be assumed that all food found in the area is dangerous. The food may contain induced radioactivity. This is unlikely to be present in dangerous quantities, because of generally unfavorable conditions and because of the short half-life of many substances. The medical officer will, however, probably be called on to give an opinion in these cases. Radioactive substances will most likely have been deposited on the food. In this case decontamination will be impracticable or impossible. Canned or otherwise protected foods may be eaten only after careful inspection and most rigorous attention to detail in removing the food from the protecting agent. If it is necessary to bring food into the contaminated area, a high degree of laboratory precision, comparable to aseptic surgical technique, must be maintained in the handling of it. Smoking should not be allowed, as the handling of tobacco adds one more hazard.

Water. If possible, no water should be drunk in the area. If canteens are to be taken in, troops must be drilled in the matter of drinking without contaminating the mouth of the canteen by wiping. If larger amounts of water must be taken in, this greatly increases the hazard. The water in an area may be contaminated as a part of the general area contamination or may have become contaminated upstream. What can be done about decontamination? (1) Boiling is useless and may be harmful. It is unlikely that all contaminants will be volatile. Boiling will then serve only to concentrate and increase the contamination. (2) Storage, although useful for short-lived isotopes, is impracticable for field operations and of little benefit for long-lived isotopes. (3) Filtration offers some promise and it is especially hoped that experimental work will point the way to practicable means of field application. (4) Chlorination and other chemical procedures are useless. (5) If we can combine precipitation and filtration, we may greatly reduce the load on precipitation. Here again, methods must be developed that are applicable to field use.

Prevention of dissemination by personnel is often of great importance. The underlying principles are always the same and may be illustrated by a discussion of the evacuation of an area. A decontamination center for area evacuation should be set up near the border of the contaminated area and all traffic in and out of the area controlled. Facilities must be provided for personnel entering the contaminated zone to remove all clothing, especially outer clothing, and change to overalls, hat, gloves, and boots. All food and tobacco should be left behind. Efficient monitoring is essential. On leaving the contaminated zone, personnel should remove hat and gloves, wash face, neck, and hands thoroughly five times with soap and water, remove remaining clothing, and then soap and thoroughly wash entire body five times. The monitor located in a room between the shower and the uncontaminated side gives permission to go to the "clean" side and put on "clean" clothing. Laundering facilities for contaminated clothing must be provided. Shoes will present a difficult problem for evacuees leaving the area.

One may work with any amount of radioactive material if proper precautions are taken; but one cannot work with even the smallest amounts without proper precautions. Troops should learn to appreciate without hysteria the dangers of exposure

IX. Essentials of Instrumentation

The detection and measurement of high energy radiation depends on the proper use of suitably constructed instruments, since nature has not seen fit to provide man with senses capable of responding to it. Without instruments even intense radiation fields will not be recognized until irreparable damage has been done. If photographic film and a few special methods are expected, all detecting devices are based on the ionization produced in gases by the incident radiation. When an ionizing agent enters a gas, it may act on a neutral atom or molecule with a force large enough to remove one or more electrons from the atom. It is most probable that two ions will be formed, and so it is customary to speak of the formation of *ion pairs*. The average energy loss per ion pair in air is about 33 electron volts.

If ions are formed in a gas subject to an electric field, they will move in opposite directions—the negative ions toward the positively charged anode and the positive ions toward the negatively charged cathode. The current flow will be extremely small, and special measuring devices are required to detect it. Because of the neutral attraction of oppositely charged particles, there is always a tendency for ions to recombine and form neutral atoms. The chance of recombination is greater the longer the time before the ions reach the electrodes. The fraction lost decreases with increasing voltage, and eventually all of the ions are collected so that there is no further increase in current. This condition is known as saturation and the maximum current is called the *saturation current.*

Instruments for measuring the amount of electric charge collected in an ionization chamber are known as electroscopes and electrometers. The *Lauritsen electroscope* is one of the most generally useful instruments for radiation measurements. The moving system is a quartz fiber about 5 microns in diameter, made capable of conducting with a thin metal coating and cemented to one arm of an **L**. Mutual repulsion causes the quartz fiber to deflect. Ions formed inside the case will neutralize the charge and the fiber will return toward its uncharged position. Another useful quartz fiber instrument is the pencil type electroscope, or *dosimeter*. This is essentially a Lauritsen electroscope modified so that the entire instrument is about the size of a large fountain pen. Instruments of this type are very useful for measuring integrated exposures. They can be made with a sensitivity such that 0.1 r. will produce about one-half of full scale deflection.

Ionization chamber instruments vary widely depending on the particular type of radiation to be detected. Short range radiation is admitted to the chamber through a suitable window. A thin mica or stretched nylon film about 0.0001 in. thick is satisfactory for alpha particles. If beta particles are to be measured, the windows need not be so thin. When a photon enters the ion chamber and is absorbed, high speed electrons are produced that travel through the gas in the chamber, producing ions until their kinetic energy is spent. For 0.2 Mev x-rays this requires a chamber about 20 cm. in diameter.

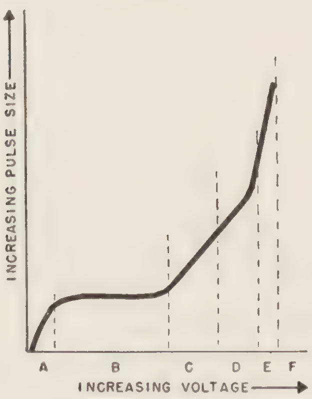


FIGURE 1. Ion chamber pulse size versus voltage.

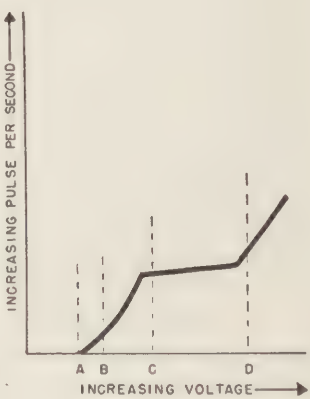


FIGURE 2. G-M tube characteristics.

If the voltage is raised still further, the gas amplification factor will continue to increase, but in region D (figure 1) the amplified pulses are no longer proportional to the number of primary ions. A sort of saturation effect begins to enter at this point, and, consequently, a few primary ions will produce nearly as many total

ions as are obtained from a large number of primary ions. There is still some difference in final pulse sizes, however, so this region is known as the region of limited proportionality. The gas amplification continues to increase with further increases in voltage, and region D gradually changes to region E where all proportionality ceases. Here a single ion pair is sufficient to produce an amplified pulse of the same size as that obtained from a large number of primary ions. This is knows as the *Geiger region* and is characterized by gas amplification factors of the order of 10^8. This is the portion of the tube characteristic commonly used for counting beta and gamma radiation. The Geiger region usually extends over a range of about 200 volts. When still higher voltages are used, the region of *continuous discharge*, F, is reached. In this region the tube is too unstable for useful operation, and care must always be taken to keep the tube voltages below the continuous discharge value. Actually the tube does not go into continuous discharge, but, rather, produces a series of closely spaced pulses from one initial ionizing event.

A second type of characteristic curve is helpful in understanding the operation in the Geiger region. Assume the tube to be exposed to a constant radiation intensity, but with the incident particles or photons having unequal energies. Pulses per second when plotted against the applied voltage yield a curve similar to figure 2. The associated electronic equipment for recording the number of pulses will not respond to the small pulses produced in the ionization chamber region where there is no gas amplification. Consequently, the curve will have a threshold, A, below which no pulses will be recorded. As the voltage is raised and the gas amplification becomes appreciable, the most energetic particles will be counted, but the weak ones will be lost. This is the region of proportional counting, AB. As the gas amplification continues to increase with voltage, more of the less energetic particles will be counted until point C is reached. Point C is the threshold of the Geiger region, CD, and here practically every particle entering the tube is counted. Point D is the threshold of the continuous discharge region.

Assume such a counter exposed to a constant amount of radiation, each ionizing particle or photon having the same energy. Each ionizing particle entering the chamber will produce a definite number of ion pairs in the gas, and these ions will proceed to the collecting electrodes where they will be neutralized and will produce a pulse of current in the external circuit. If, now, the size of the pulse is plotted against the voltage applied to the electrodes, a curve similar to that of figure 1 will be obtained. Regions A and B represent the normal ionization chamber working conditions where the only ions contributing to the pulse are those produced by the original radiation. Over region C there is some gas amplification occurring very close to the central wire. In this region the gaseous amplification is quite stable for any given voltage and does not depend on the number of initial ions present. Thus, if the voltage is adjusted to a value such that the gas amplification factor is 1,000 and an incident beta particle produces 100 ion pairs, the pulse received at the electrode will be 10^5 ions. Under the same voltage conditions an alpha particle producing 10^5 primary ion pairs will yield a pulse of $10^5 \times 10^3$, or 10^8 ions. Because of the rather strict proportionality between the amounts of initial and total ionization, this portion of the curve is known as the *region of proportionality*, and a counting tube operating in this region is called a *proportional counter*. A proportional counter can be used to measure alpha particles or neutrons in the presence of strong beta and gamma radiation.

A small portable chamber should have the same absorption for x- and gamma rays as the air in the standard chamber and should also have the equivalent of the long air paths for the absorption of the high energy electrons. Chamber walls are regularly made of bakelite or plastics, both containing a high percent of carbon atoms. Since human tissue is composed chiefly of carbon, oxygen, nitrogen, and hydrogen, such an instrument will simulate absorption by the body. Ionization chambers designed on these considerations are known as *thimble chambers*. One

successful thimble chamber instrument that is not entirely satisfactory for survey purposes is the *condenser gamma meter*. The chambers must be charged, left in the radiation field for an appropriate time, and then read with the meter. If a large contaminated area were to be surveyed, an enormous number of such chambers would be required. Such an area would require an instrument that would give a steady deflection proportional to the amount of radiation striking the chamber. Unfortunately, ionization currents are too small to be measured with portable meters, and it is necessary to use other means. It is perfectly feasible to measure currents of this order with suitable vacuum tube circuits.

Geiger-Müller (G-M) counters take advantage of the gas amplification that can be obtained when high accelerating voltages are applied to an ionization chamber. When an ion has an energy greater than the ionization energy of the gas molecule, it may produce secondary ions on collision. The secondary ions formed will in turn be accelerated by the electric field and may produce further ionization. This cumulative effect is known as *avalanche ionization*. If a total of A ion pairs results from one original pair, the process is said to have a gas amplification factor of A. In practice, A varies from about 10 in gas-filled photoelectric cells to 10^8 in some G-M counters. At a pressure of 10 cm. of mercury, gas amplification can be obtained at voltages of 250 to 1,500 volts depending on the gas and the tube dimensions. G-M counters usually have a cylindric cathode 1 to 10 cm. in diameter with a length 2 to 10 times the diameter. The anode consists typically of an insulated axial wire 0.001 to 0.005 in. in diameter.

The Geiger region is known as the *plateau*, and it is obviously desirable for a tube to have a long, flat plateau, since here the counting rate does not depend strongly on the applied voltage. To obtain desirable plateau characteristics the filling gas and pressure must be carefully chosen, and the central wire must be free from dust, sharp points, or die marks. Oxygen and water vapor are particularly undesirable and must be completely removed before filling. Argon is a very satisfactory gas and is used in practically all counters. Near the central wire a large number of electrons and positive ions will be formed in the avalanche. The electrons have a small mass and are already close to the central wire, so they will move toward it with high velocities and will be completely collected by the wire in 10^{-6} sec. or less. The positive ions, on the other hand, have to travel out to the negatively charged cylinder. Since they have comparatively large masses, they move much more slowly than the electrons. The positive ion cloud will reach the cylinder in about 10^{-3} sec.—long after the electrons have been collected at the wire. As a positive ion approaches very close to the cylinder, it will pull an electron from the cylinder and become a neutral molecule. In general, the electron will go into one of the upper energy levels so that the molecule, although neutral, will be in an excited state. The molecule will, however, promptly return to the ground state and in so doing will radiate a characteristic series of spectral lines. Some of these lines will be in the ultraviolet region of the spectrum and, consequently, will have sufficient energy to liberate photoelectrons from the metal cylinder. With high tube voltages a single photoelectron will be sufficient to start a second avalanche, and thus the entire process will be repeated over and over again.

It is possible, however, to construct counters in which the discharge can be stopped. These are known as *self-quenching* or fast counters. A self-quenching counter can be produced by adding to the usual filling gas a small amount of a polyatomic vapor, such as alcohol or xylene. These complex molecules strongly absorb ultraviolet light, and by this mechanism the photoelectric omission at the cathode is prevented. Most of the polyatomic molecules introduced to make self-quenching counters are vapors at room temperature, and these counters are likely to show a sensitivity that changes with temperature. A further disadvantage lies in the fact that some of the quenching gas is dissociated at each discharge, and so these counters have a limited life. A very satisfactory self-quenching counter can be made by filling the tube with 10 percent alcohol and 90 percent argon to a total pressure of 10 cm. of mercury. With

a nonself-quenching tube, an auxiliary circuit must be used to stop the discharge.

Any counter will give counts when placed in a neutron field, but better results can be obtained with specially designed tubes. To detect slow neutrons, the counter is filled with boron trifluoride, which is a gas at room temperature. A slow neutron may produce a nuclear reaction with the boron. This reaction liberates a considerable amount of energy, and the alpha particle and the recoiling lithium will have sufficient kinetic energy to produce heavy ionization that will trip the counter. By using the counter in the proportional range, it is possible to obtain a count for each disintegration even in the presence of large beta and gamma intensities. The capture probability decreases with the neutron velocity, so the reaction is not efficient for fast neutrons. Fast neutrons may be detected through the recoil atoms they produce when they collide with the gas atoms in the counter. The recoil atoms produce intense ionization, and, hence, if the counter is adjusted to the proportional range, the counter will discriminate against beta and gamma radiation. Fast neutron counters have a rather low efficiency because of the low cross section for the collision process. Neutron counting is complicated by the change in behavior with velocity, and the present neutron counters are far from satisfactory.

None of these devices gives an absolute measure of radiation intensities. It is, therefore, necessary to calibrate them in terms of known standards. This is not difficult if a gamma ray calibration is required in terms of roentgens. It has been established by careful measurements that 1 mg. of radium, in equilibrium with its products and inclosed in 0.5 mm. of platinum or its equivalent, will produce an intensity of 8.4 r. per hour at a distance of 1 cm. The inverse square law can be used to calculate the intensities at other distances. Standard x-ray sources, properly aged and carefully calibrated, are available from the National Bureau of Standards. Calibration of x-ray measuring instruments should be accomplished against primary standard ionization chambers or carefully calibrated secondary standards by a well-equipped laboratory such as the National Bureau of Standards or by a reliable instrument manufacturer.

TABLE I

Emulsion	Useful sensitivity range (roentgens)	Emulsion	Useful sensitivity range (roentgens)
Type K	0.05– 2.0	Kodalith 6567	70– 700
Type A	1.0 – 10	Kodabromide G–3	400– 8,000
Cine positive 5301	5 – 80	548–0, double coat	2,000–10,000
Cine positive fine grain 5302	40 –400	548–0, single coat	5,000–20,000

In making alpha and beta particle measurements quite different considerations enter. Radioactive materials emit particles in all directions with equal probability, and, in general, a chamber or G-M tube will intercept only a fraction of the total emission. For example, if the active material is spread in a thin layer on the bottom of the chamber, only one-half of the ejected particles will reach the gas and produce ionization. It is then necessary to calibrate the chamber in terms of a known radioactive material. Various members of the naturally radioactive series are useful for this purpose. Photographic materials are also important tools for the measurement of radiation, since high speed particles and high energy photons produce developable images. Although photographic films and papers lack the accuracy attainable in the laboratory by electrical methods, they still play an important role in radiation measurements. A film is one of the simplest detectors of radiation, is small and light, can be obtained with a wide range of sensitivity, provides a permanent record of exposure, and has no complicated electronic circuits to get

out of adjustment. For many applications these facts more than outweigh the disadvantages of film processing, the time required to obtain a measurement, and the variations inherent in photographic materials. Table I lists a series of emulsions that have proved useful for measuring beta and gamma radiations. It can be seen that a single emulsion will cover an exposure range of about 1 to 10.

Photographic film meters are usually made into packets of dental film size (1.25 by 1.75 in.) and covered with an opaque wrapping to protect the film from visible light. Any combination of suitable emulsions can be put into a single packet. A cross of thin sheet lead about 1 mm. thick is attached to the packet. This absorber is sufficient to stop all beta particles so any darkening under the cross will be due to gamma rays. The cross also serves to enhance this darkening because of the larger number of electrons ejected from the lead. The regular wrapping is sufficiently thin to permit the penetration of all but low energy beta particles. Thus the film can be used to measure both beta and gamma exposures. In general, film processing is conducted in accordance with the manufacturers' recommendations, but variations may be used. Whatever procedure is used, it is most important to control time and temperature as accurately as possible. The developer should be in a tank surrounded by a constant temperature bath, and the films agitated throughout development. The importance of time and temperature control, scrupulous darkroom technique, and the use of fresh chemicals cannot be overemphasized.

Special emulsions are now available that are almost insensitive to visible light, and beta and gamma radiations, but will respond to heavy particles such as protons, deuterons, or alpha particles. These particles have such a low penetrating power that the emitting substance must be placed in direct contact with the emulsion. These emulsions are not used for personnel monitoring, but rather to detect alpha particle contamination. These emulsions will detect alpha particles in the presence of strong beta and gamma radiation, and under conditions that make the operation of electrical alpha particle detectors uncertain if not impossible. With weak exposures the plate will not be uniformly darkened and individual alpha particle tracks can be seen by using a microscope. Since alpha particles are emitted with an energy characteristic of the emitting nucleus, the track lengths may frequently be used to identify the alpha emitter. The various film emulsions can be used to make radio autographs of specimens containing radioactive materials. By exposing sections of the specimen it is possible to determine the cross-sectional distribution as well. The resolving power of photographic emulsions for determining the precise position is limited, and it is scarcely possible to determine the location of radioactivity to less than $^1/_{100}$ mm.

X. Protection Against Atomic Bombs

Protection against atomic bombs may be divided into passive defense and active defense. The important effects of the atomic bomb against which protection must be developed are (1) the blast or shock wave; (2) visible light, ultraviolet, and infrared radiations; (3) nuclear radiation; and (4) psychological effects.

PASSIVE DEFENSE AND PROTECTION

Blast. The effects of the atomic bomb rapidly decrease in intensity as one moves away from the point of detonation; thus, distance is always the best protection. Primary shock, or blast damage, is defined as the compressive and tearing action of the shock wave on the human body. When one interposes between the blast and the body an object of strength similar to that of an ordinary wall, this form of damage is effectively reduced. Primary shock is thus of importance only when a person is in the open, in which case he is exposed simultaneously to lethal amounts of other effects of the atomic bomb. Living things are remarkably resistant to blast damage and are much stronger in this respect than normal buildings. Underground shelters and normal reinforced concrete buildings protect against this effect

very close to the point of detonation. Petechial hemorrhages of the lung occur from blast damage in its mildest forms. In its severest forms major abdominal hemorrhages appear.

Secondary shock, or blast damage, is caused by flying objects hitting and lacerating the body. A shock wave is very much like a wind of several hundred miles per hour, arising instantaneously, and lasting for about a second. This wind is strong enough to throw the body several feet. It also breaks windows, knocks down plaster, and throws other objects around with great violence. When these objects strike a person secondary shock damage results. There are many things a person can do for himself to reduce his chances of this type of injury if he has some advance warning of the detonation. He should keep away from windows and lie flat on the floor or ground. He should avoid standing under overhanging cornices, chimneys, and other heavy objects that are easily knocked down. Underground installations or shelters greatly reduce this effect, because very little of the air shock is transmitted through the ground and thence into shelters or basements. In Japan, this form of injury combined with burns accounted for most of the casualties. The rapid follow-up of the fire on the blast damage caused many deaths among the injured. Injuries of this type require evacuation and hospitalization. In the case of primary shock damage there is an amazingly small boundary zone. One is either killed immediately or is all right after a few minutes, so far as this effect is concerned. There is much that can be done in the design of vital installations to reduce damage from these secondary shock effects.

Flash burns are injuries created by direct exposure to the visible and near-visible radiation emanating from the point of detonation. The thinnest type of nontransparent material will shield effectively from this effect. Light-colored clothing is particularly good as it reflects almost all this radiation. Dark clothing will not transmit this radiation but will catch fire and produce flame burns on the skin beneath the clothing. This form of damage is important only when a person is in the open and in direct line of sight with the point of detonation. Because of the nature of the atomic bomb, this form of damage occurs at greater distances than those caused by any other effect.

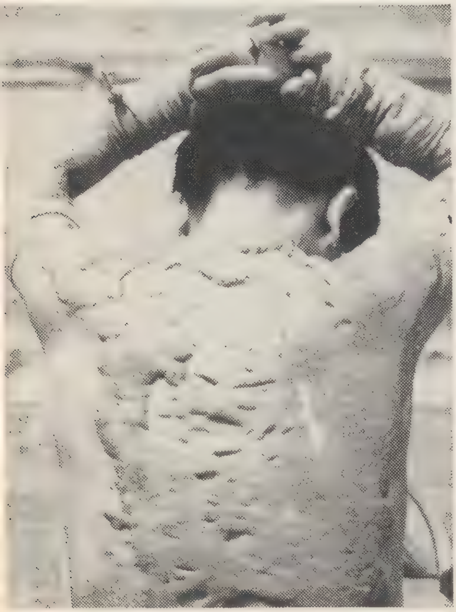
Flame burns are produced by fire started in inflammable materials or buildings. These were prevalent in Japan, but they would occur to a lesser degree in an American city. This possibility of fire and subsequent injury can be greatly reduced by making structures less inflammable. The development of large quantities of adequate fire-fighting equipment and trained personnel can furnish great protection. To reduce this form of damage it will be necessary to have fire-fighting equipment and personnel so located that a major proportion will not be wiped out by the detonation. Accounts from Hiroshima and Nagasaki point out the inadequacy of Japanese fire-fighting equipment and procedures. In both cities, about 90 percent of the equipment and personnel for these duties were wiped out immediately. Major efforts should be directed to reducing the possibility of flame burns, not only because they produce a large number of casualties, but also because these casualties need so many trained persons and so much equipment for treatment and hospitalization.

Nuclear radiation. The use of nuclear radiation in warfare presents new problems for both the military and the civil population. These effects are not only important but complex, as they may be caused by external and internal radiations and may be immediate or delayed. For all nuclear radiation effects, distance is by far the best protection. Immediate radiation effects are produced in a matter of a few thousandths of a second after detonation. With the atomic bomb, about 99 percent of the nuclear radiation produced comes out in the first fraction of a second after the detonation. It consists of penetrating radiations that come from outside the body and therefore constitute an external hazard.

Large quantities of gamma rays are produced almost immediately by the detonation and radiate in all directions. These rays travel in a straight line as does light.

Hemorrhage and stomatitis. (Patient was outdoors when injured.)

Keloid following burn. (Photograph taken 18 months after injury.)



Keloids, contractures, and ulcers

Photograph of siblings, showing similar degrees of epilation resulting from equal exposure to gamma radiation

They are highly penetrating, and it takes a large amount of material to absorb and stop them. It is important to realize the directional and shadow producing characteristics of this radiation. One does not need shielding on all sides but merely on the side of the detonation. In shielding against gamma radiation the important thing is the weight of the material that is between the body and the source. The chemical characteristics of the shield are of no importance. Lead is often used in laboratories where gamma radiation or x-radiation occurs. This is a suitable substance because it occupies a very small volume in comparison to its weight. The effectiveness of a shield is most often described by means of thickness of the material that is necessary to reduce the intensity to half the initial amount. This is called the half-thickness of that material. The approximate half-thickness of common construction materials are 1 in. for steel, 3 in. for concrete, and 4 in. for wood or earth.

Neutrons also constitute an external hazard at the time of the detonation. They are not as effective at great distances as the gamma rays, but they require consideration because, being uncharged particles, they are difficult to stop and shield against. Shielding is not as simple as in the case of gamma radiation, because the weight of the shielding material is not the important factor. Instead, the important characteristic is the ability of the particular element or compound to slow down and then capture neutrons. The neutrons that occur in the detonation of an atomic bomb are essentially fast neutrons. Substances such as cadmium and boron capture slow neutrons to an amazing degree; but, since these neutrons are not slow, these substances are of little value in defense against the atomic bomb. The best substances are those with low atomic weights. Hydrogen, the lightest of all substances, is the best; hence, in shielding against neutrons, the best substances for their weight are those containing large amounts of hydrogen, such as water or paraffin. The approximate half-thicknesses of common materials are between 3 in. and 12 in. for steel and about 6 in. for concrete, earth, wood, and water. Since neutrons, like gamma rays, travel in a straight line from the point of detonation, radiating in all directions, the shielding need be only between the person and the source.

Delayed radiation. About 1 percent of the nuclear radiation produced by an atomic bomb is not produced immediately, but comes from the decay of the fission products. In an air burst, where the fireball and mushroom cloud containing the fission products go up in the air to be dispersed by the wind, this delayed radiation is negligible. In an underwater burst, or possibly a surface land burst, a base surge will probably occur. This cloud, moving close to the ground, contains a large proportion of the fission products. As this cloud sweeps out over ships or cities, it surrounds buildings, people, and equipment. The radiating material is then extremely close to a person. The relatively small amount of radiation that is left after the detonation is greatly enhanced because of its proximity. This base surge, in comparison to the mushroom cloud after the air burst, produces radiation intensities on the ground that are higher by many thousandfold. This is due solely to the fact that the base surge can surround individuals on the ground. When it is realized that at Bikini this base surge moved over an area of about 5 sq. mi., this is seen to be a very real hazard. It takes time for this cloud to move, and, as the radiation from it is only of importance when it surrounds the point in consideration, there is available a varying amount of time in which to get out of the way or to dodge the cloud. This base surge moves with varying speeds. Initially it spreads out at about 50 m. p. h. Its speed constantly decreases until it is dispelled. For this cloud to spread over its maximum area requires several minutes. If one is in a city, great protection will be afforded if one gets down into a basement or sub-basement, or into an air-raid shelter. It is of importance also to note that this radiation from the base surge is nondirectional, as it comes from all points in the cloud. Hence, any shield that is devised must be on all sides, including the top, of the location considered.

Delayed gamma radiation from the base surge is similar to immediate gamma radiation, except in its nondirectional characteristics. The shielding requirements are similar to those in the previous situation, in that the same half-thicknesses are applicable. There are no delayed neutrons of significance; hence, special shielding is of no importance in this problem. In the delayed situation we also have important beta radiation. Immediate beta radiation occurs but does not travel a very great distance from the source, because of the efficient shielding furnished by air. Where the base surge is surrounding the location in question, beta radiation is important, because the half-thickness of air is about 4 yd. Normal clothing furnishes sufficient shielding to beta radiation. Similarly, thin walls and the glass in windows are adequate. It is, of course, nondirectional and comes from all sides. The extent of the external hazard furnished by beta radiation is not well understood. It is believed comparable to that of gamma radiation when a base surge has been created. Alpha radiation occurs from the nonfissioned plutonium and uranium. This radiation constitutes no external hazard, as the skin furnishes adequate shielding. All the alpha rays are absorbed in the epidermis with no resulting damage to living tissues.

Internal radiation gets into the body through inhalation, ingestion, or injection. This is a delayed hazard and is possible only where one is in the base surge, the mushroom cloud, or an area over which the base surge has previously passed. The internal hazard generally occurs only where there is also an external hazard. If one is exposed to the base surge or is in the mushroom cloud, the external radiation is often lethal without any consideration of an internal hazard. Particularly if one is working in a highly contaminated area after the detonation, there is a significant, but not necessarily lethal, degree of external hazard; but there is also a very great internal hazard. This is created by disturbing the dust and usually enters the body through inhalation. An additional hazard exists from eating with contaminated hands and thus getting the active material into the body through the mouth.

In the case of an atomic explosion, a small amount of this radioactive material is in the form of a true gas or vapor. Almost all of it exists on particles of dust or droplets of water. These contaminated particles have a size range from 0.1 to 10 microns. The filter in a modern gas mask such as the assault mask is believed to give adequate protection. This filter is extremely efficient. It is quite possible that new masks will be devised that will protect against atomic, biologic, and chemical warfare. Such a development is highly desirable. Protective clothing would be required for workers entering contaminated areas. It would probably be permeable clothing. Its main requirement is that it should be disposable. Its functions would be to keep contaminated material from the skin and possible later entry into the body. Disposability is desirable, as these materials cannot be rendered harmless by any physical or chemical means.

Collective protectors with filters or inclosed air-conditioning systems are probably indicated for vital installations and underground shelters in anticipation of atomic warfare. Such items would prevent the highly contaminated air of the base surge from entering installations that otherwise would furnish adequate protection against the effects of the atomic bomb. The development of decontamination techniques and facilities is indicated to reduce the long-term possibility of personnel becoming contaminated and later having active material enter the body through the respiratory and digestive tracts. Such techniques will probably consist of washing away, carrying away, or burying the active material.

Education. In an attack on a modern city it is believed that about 50,000 deaths would result from a single bomb. It is felt that, if the individual civilian and soldier in such a city were adequately trained as to what he could do for himself after the detonation occurs, perhaps 10,000 lives could be saved. The development of atomic defense for the individual will be the subject of much work in the future. The education of large numbers of persons, both civilian and military, for special jobs in atomic warfare is important and will probably be given to such people as radiologic safety personnel, medical officers, civilian doctors, and civil defense tech-

nicians. The method by which the individual indoctrination and the specialized training is given will determine to a large extent the psychological preparation that will be attained in a population. It is highly desirable that we impart the proper degree of knowledge to all so that each individual has a respect for the special hazards of atomic warfare, thereby avoiding the undesirable extremes of excessive fear or ignorance. This will be a difficult job and the Nation is far from attaining this goal at present.

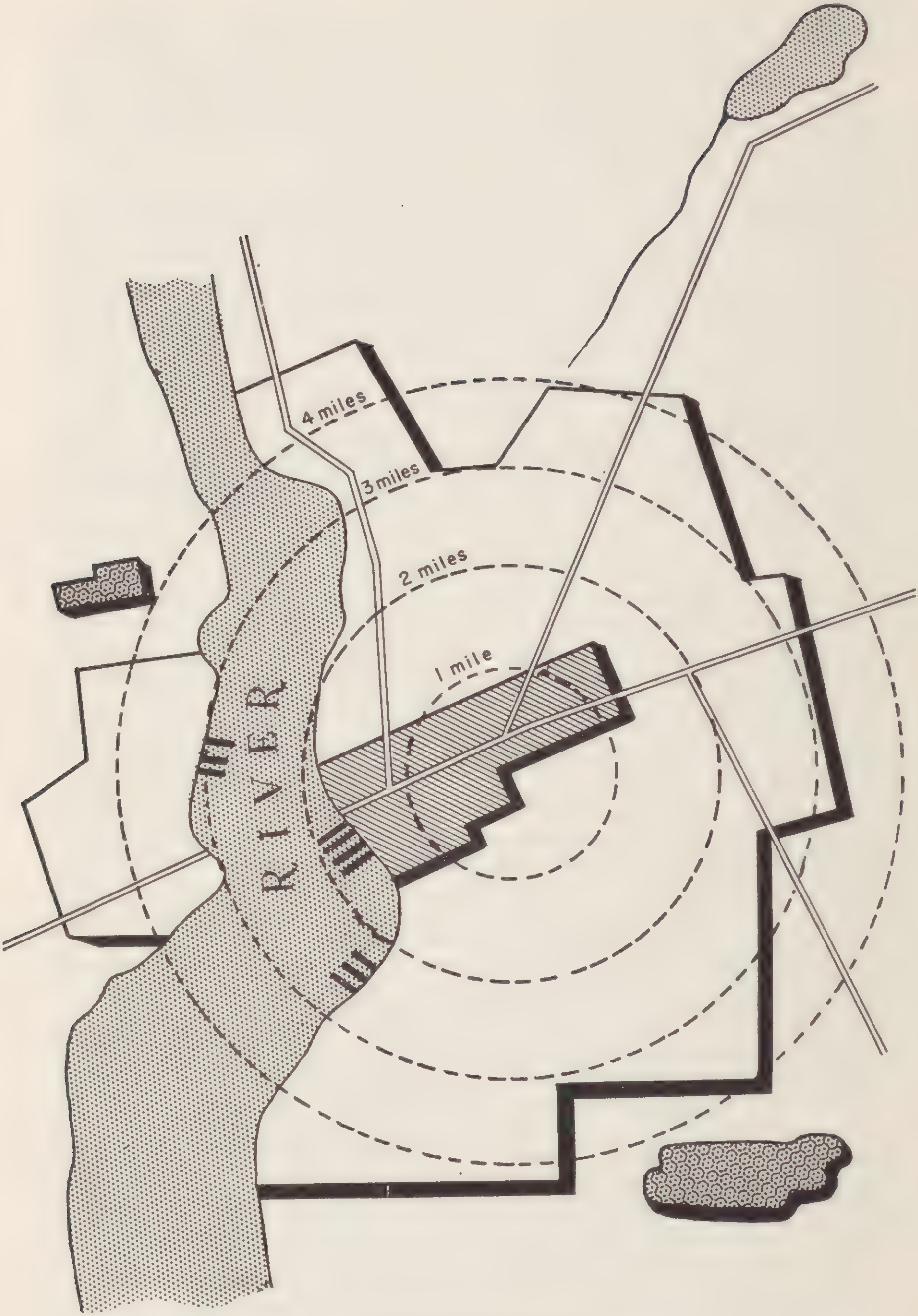
A large amount of detailed defense planning will be required for the protection of the Nation. It will include large-scale training of such specialists as fire fighters, evacuation control personnel, first-aid personnel, and decontamination groups. Large stock piles of food supplies, medical supplies, and disaster equipment will be required in relatively invulnerable locations. Preparations will be required for mutual aid between cities and major installations. All civil and military groups must be equipped and trained in the detection and isolation of contaminated areas. This new hazard created by nuclear radiation is the one hazard that may not be detected by any of the physical senses. It requires special instruments and special consideration. With sufficient indoctrination and a few minutes' advance warning of an attack, it is quite possible that a 50 percent saving in casualties can be effected. This establishes the fact that development of advance detection techniques and warning signals is of the greatest importance to insure the continuation of our present existence.

ACTIVE DEFENSE

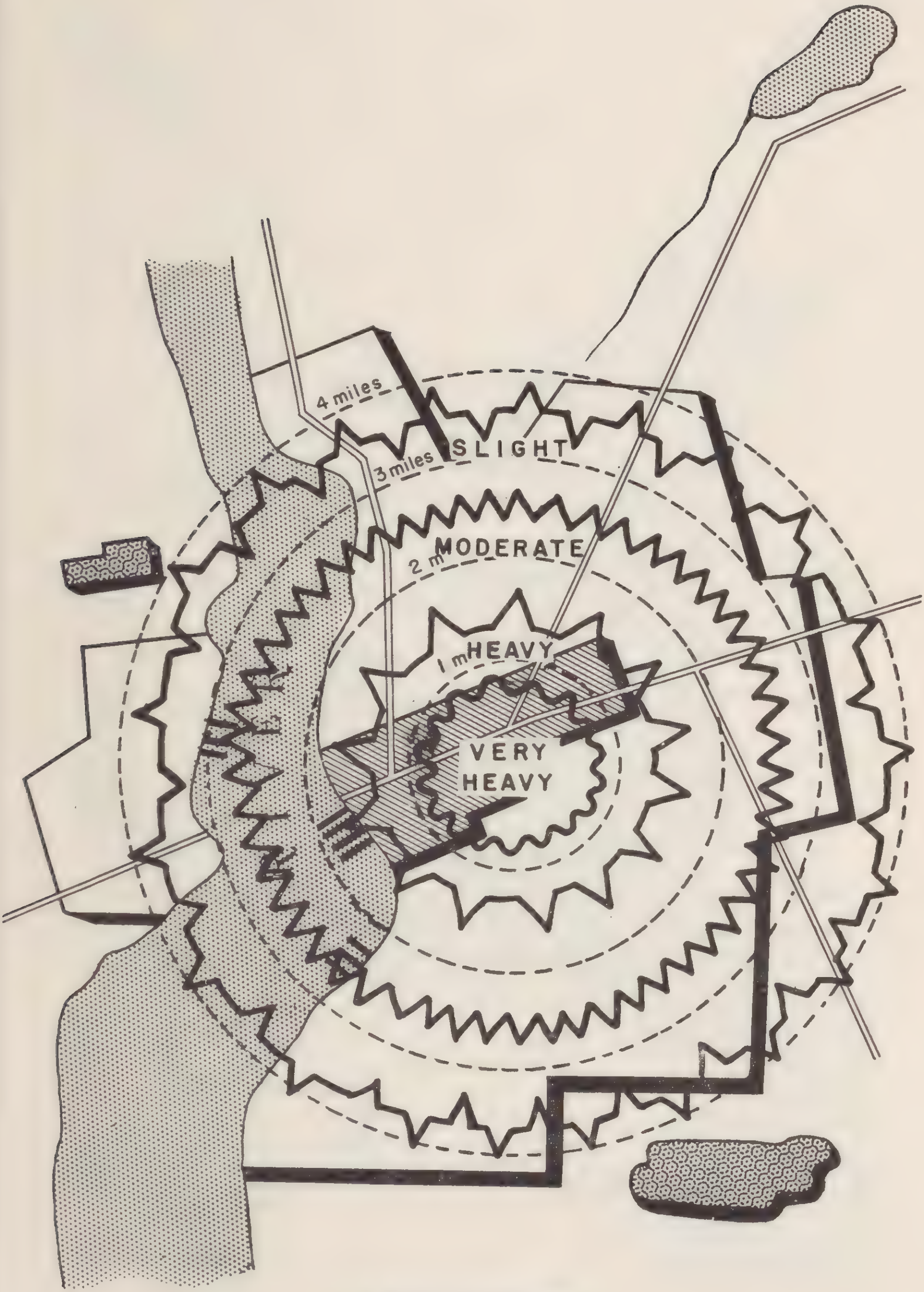
Of less direct importance to the medical profession but of the utmost importance to the Nation is active defense, which means the prevention of an atomic attack. Regardless of our degree of preparation and protection, large numbers of casualties and a more important amount of disorganization and dislocation will occur. The attempts of the United Nations Organization to set up machinery to insure peace in the future, if successful, will be the greatest protection we can have against the atomic bomb. The basic responsibilities of military organizations require that they assume that war will occur.

Regardless of the political situation, the military organizations must constantly maintain the highest level of preparedness. In the case of atomic warfare this will consist of extensive stock-piling of all weapons, including atomic bombs. It will require readiness of retaliation forces. Because of the nature of the atomic bomb, it will require extensive protection of our ability to retaliate and conduct an offensive war. As was seen above, advance warning is most important—thus an efficient foreign intelligence corps is vital. Some persons have raised the provoking thought that, because of the capabilities of the atomic bomb, we shall lose an atomic war unless we attack first, assuming the enemy has atomic bombs.

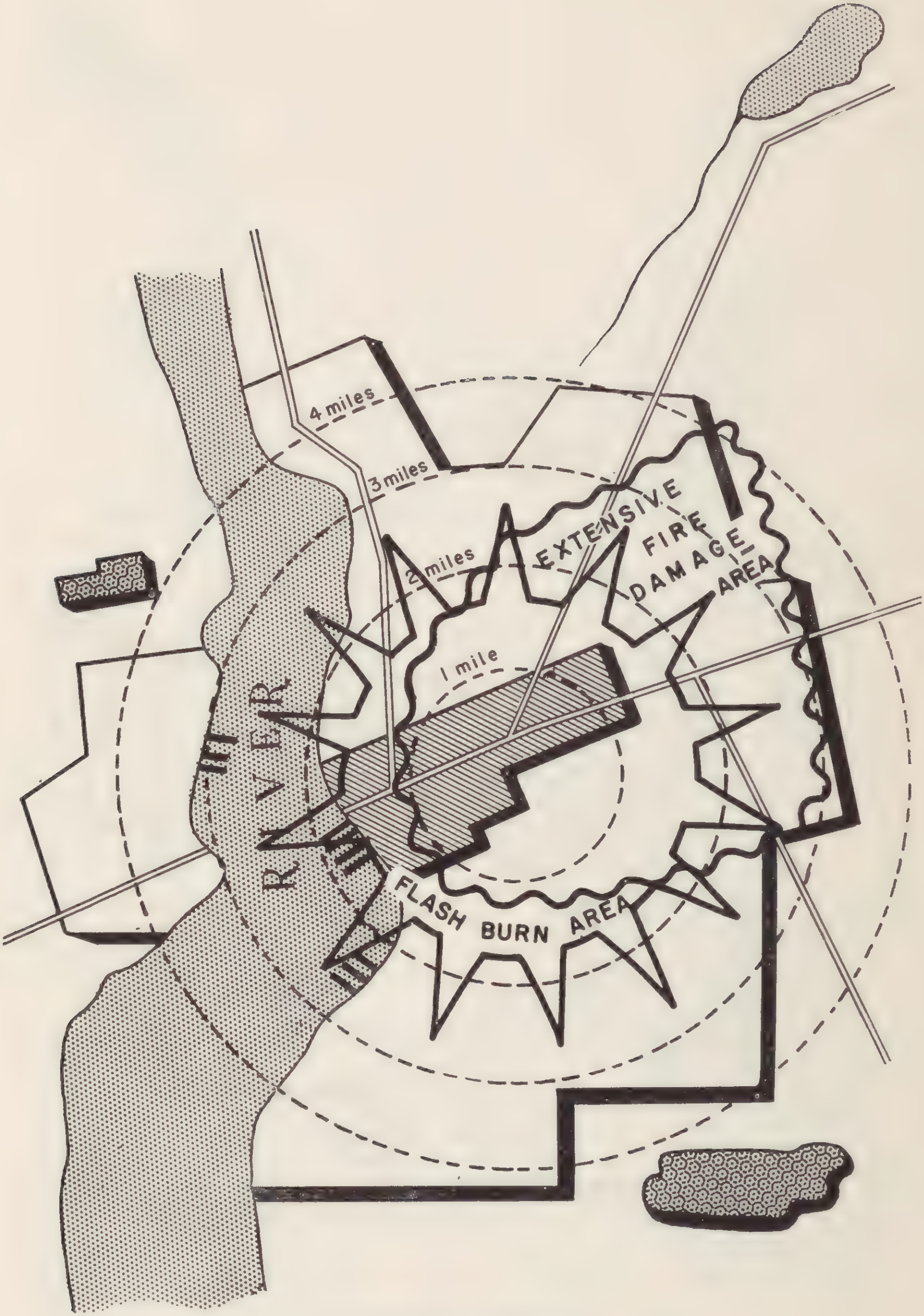
A vital part of active defense that is erroneously played down in articles in the press is the assumed futility of interception of an atomic bomb carrier. Within the last few weeks our authorities on guided missiles have stated openly that it is their belief that guided missiles cannot be used to carry an atomic bomb for at least ten years. The military authorities must concentrate on the intervening years in which it is anticipated that a manned aircraft is the most likely vehicle. We have had only a fair degree of success in the interception of aircraft on bombing missions. There is no scientific reason why our degree of interception cannot be raised to nearly 100 percent if sufficient money, time, and technical ability are put on the problem. Atomic warfare presents a truly horrible outlook. It is our duty to push to the utmost any procedure that could possibly reduce its effectiveness against us.



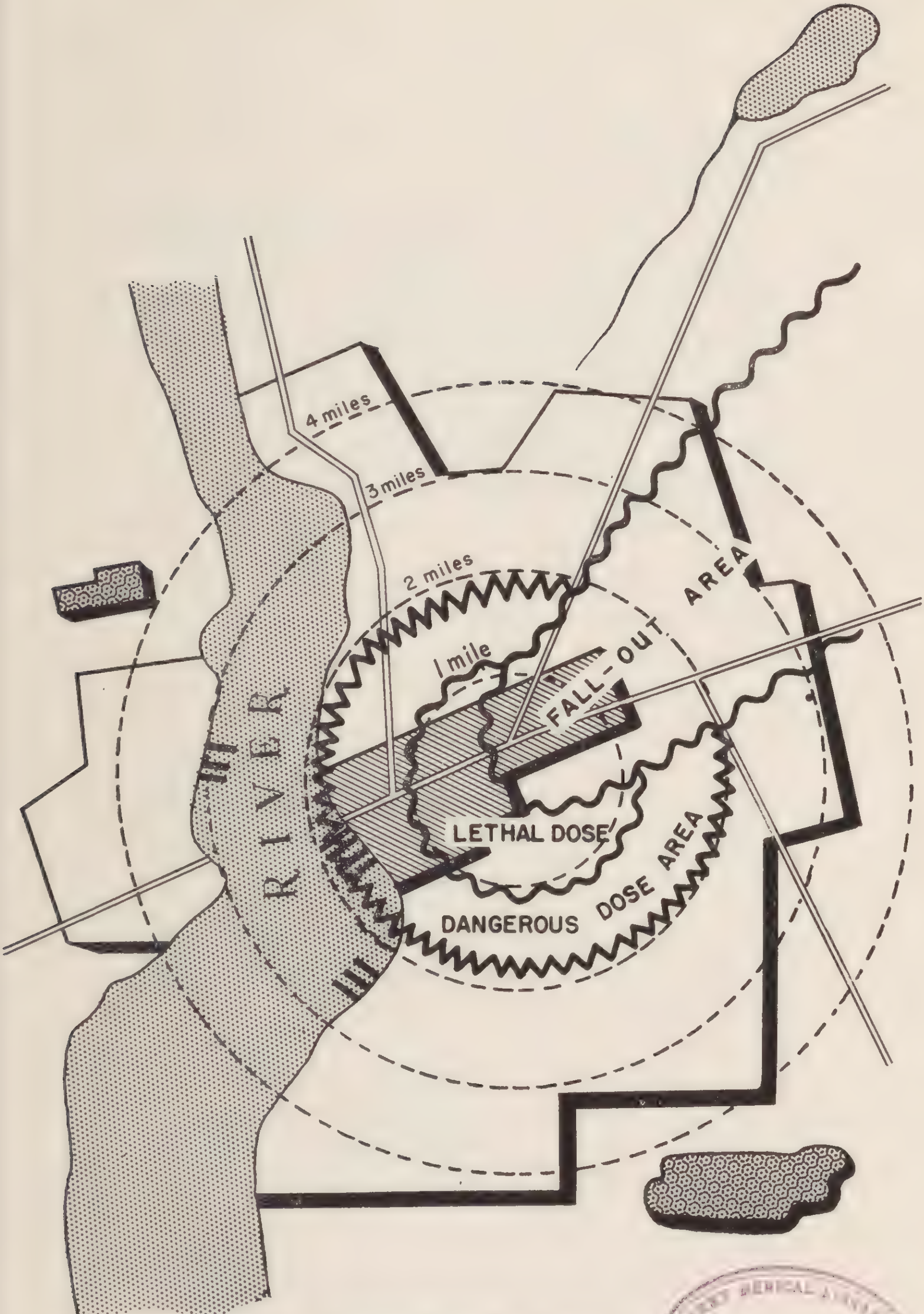
Typical American city



A-Bomb blast damage



A-Bomb thermal effect



A-Bomb lethal dose area

For the Record

It is no news that the war has fostered amazing advances in science, not the least of which are the forward steps of medicine. The Army Medical Department with its expanded research and development program is preparing to apply many of these scientific advancements to the postwar world. Thus the Medical Department is keeping pace with the changing conditions of global health needs by developing the practice of total medicine.

Doctors who are looking for outstanding training in any of the many specialties in medicine and surgery will find that the Army Medical Department offers some of the best training in the world. They receive instructions and experience under the guidance of top-flight Army and civilian teachers. They use the latest equipment — work in large general hospitals and laboratories. They learn new techniques which few civilian doctors have an opportunity to master.

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